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SURVIVAL OF PATHOGENS IN SEWAGE STABILIZATION PONDS

Quentin M. Mees, et al

Arizona University
Tucson, Arizona

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"SURVIVAL OF PATHOGENS IN SEWAGE STABILIZATION PONDS"

FINAL REPORT

NIH RESEARCH GRANT
No. E-3436

Quentin M. Mees, Professor, Principal Investigator
Department of Civil Engineering

J. R. Hensley, Research Biologist
Department of Civil Engineering

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FOREWORD

This publication represents the final report of investigations supported by the National Institutes of Health Grant No. E-3436. The following individuals carried primary responsibility in conducting the study:

Quentin M. Mees, Professor, Department of Civil Engineering
Principal Investigator

Jack R. Hensley, Department of Civil Engineering
Research Biologist

The generous and most helpful assistance and cooperation of personnel of the Bureau of Environmental Health of the Arizona State Department of Health, and of the Sanitary District No. 1 of Pima County are gratefully acknowledged.

Appreciation and thanks are given to the following persons for their valuable assistance during various phases of the project:

Bill B. Dendy, Eugene W. Dooley, Stanley J. Dea, Edward F. Geiser, E. Lee Klink, William C. Pisano, and Steven A. Deming.

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1. INTRODUCTION

1.1 PURPOSE OF STUDY

In semi-arid areas where water supplies are being depleted at alarming rates, re-use of water is of paramount importance. Whether re-use takes the form of irrigation, recharge, or industrial use, health protection becomes a factor of prime importance. Since agricultural re-use of the effluent from stabilization ponds has become more widespread, it has been recognized that there is a great need for information concerned with the ability of certain pathogens to survive the phenomena of treatment within a facility of this type. This investigation was initiated in an attempt to determine the survivability of amoebic cysts, intestinal flagellates, and ova of helminths at various phases of the stabilization process. Only those organisms pathogenic to man were to be investigated.

1.2 RESEARCH PLAN

The development of data which could be used to draw conclusions related to the survivability of the selected pathogenic organisms required that several well defined objectives be considered:

1. Determination of the incidence of the organisms in the local sewage system.
2. Development of a reliable method for culturing the organisms.
3. Development of a reliable method for reclaiming the organisms from the stabilization pond following either natural or artificial seeding.

4. Collection of engineering data which could conceivably be related to survivability.

Although it was realized that some time would be required to obtain the first three objectives, it was felt that the collection of engineering data should begin as soon as sampling and analytical procedures could be worked out. As a result of this decision, collection of biological and engineering data were carried on simultaneously.

1.3 ENVIRONMENTAL FACTORS

1.3.1 Stabilization Pond Location

The sewage stabilization pond used for the investigation is owned and operated by the Pima County Sanitary District No. 1 and is located approximately 8 miles northwest of Tucson near the Santa Cruz River, as indicated in Fig. 1.1. This pond was constructed in 1960. During the course of the investigation, a second pond of approximately the same size, as well as a smaller pond, were added to the treatment site. Details of the three ponds are presented in Fig. 1.2. Although major sampling activity was conducted in the west pond, samples of the effluent from the east pond were also analyzed. Since the area served by the pond is primarily residential, domestic sewage constituted the bulk of the flow.

The overall dike centerline dimensions of the west pond are 200 by 500 feet with the larger dimension oriented in a north-south direction. The dikes have a top width of 10 feet and interior and exterior slopes of two horizontal to one vertical. Influent is

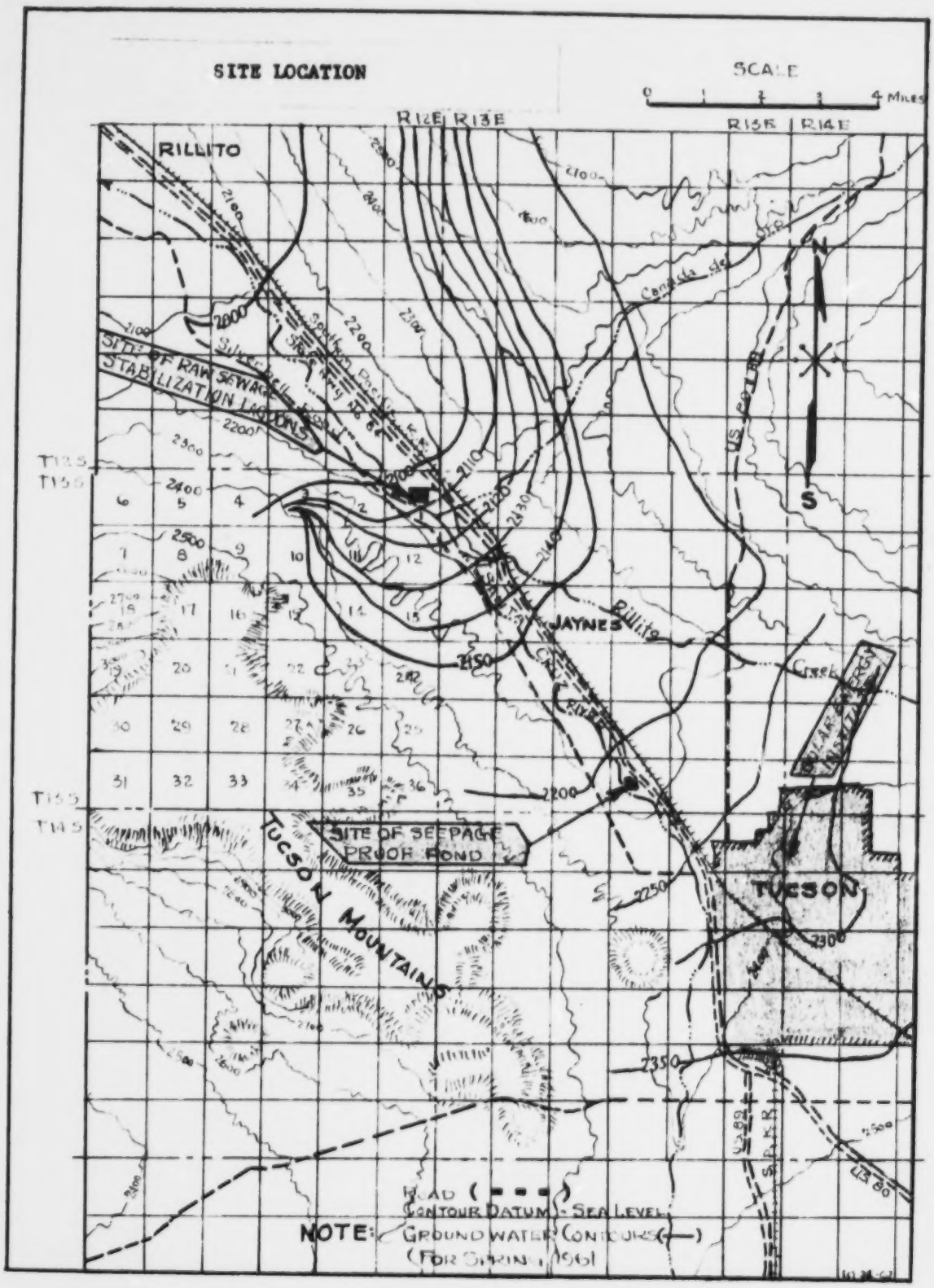
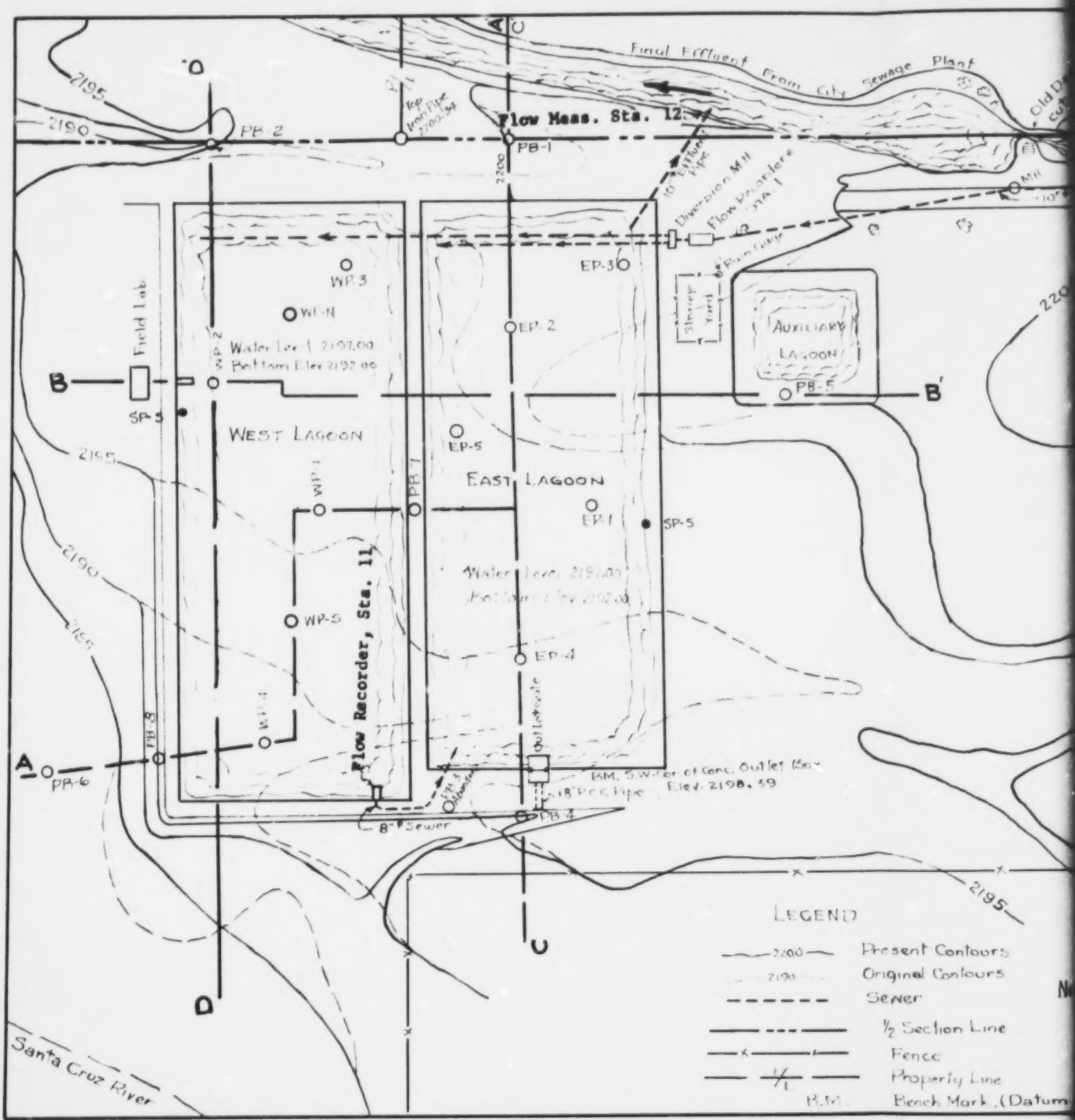
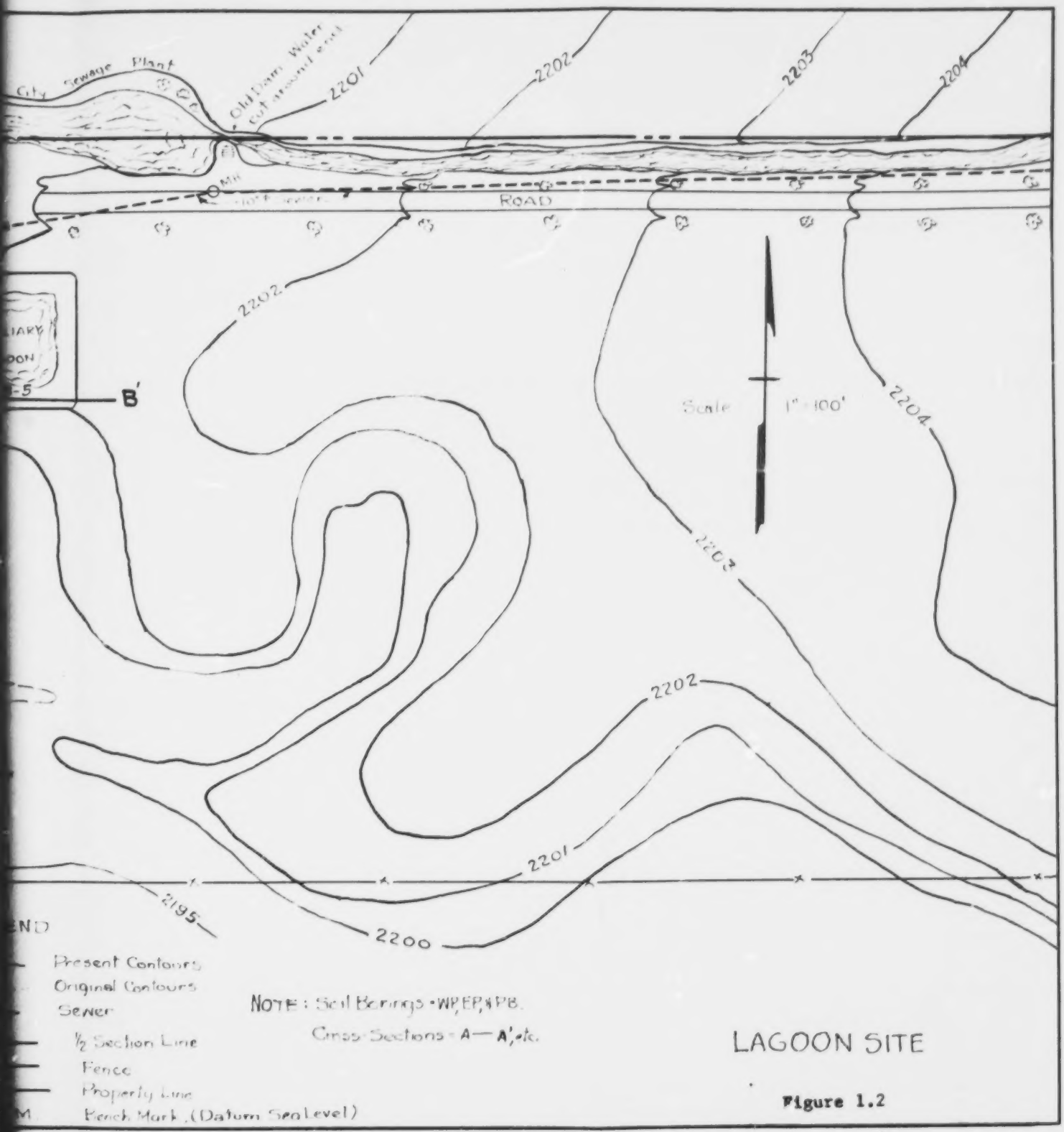

SITE LOCATION
SCALE
0 1 2 3 4 Miles
R12E R13E
R15E R14E
RILLITO
SITE OF RAW SEWAGE STABILIZATION LAGOONS
T13S
T14S
JAYNES
Rillito
Creek
SITE OF SEEPAGE PROOF POND
TUCSON MOUNTAINS
TUCSON
S.P.R.R.
U.S. 80
U.S. 89
N
S
HEAD (- - -)
CONTOUR DATUM - SEA LEVEL
NOTE: GROUND WATER CONTOURS (——)
(FOR SPRING, 1961

Figure 1.1


Final Effluent From City Sewage Plant
Flow Meas. Sta. 12
PB-2
PB-1
Diversion MH
Flow Recorder Sta. 1
EP-3
EP-2
WP-3
WP-N
Water Level 2197.00
Bottom Elev 2192.99
Field Lab
SP-5
WEST LAGOON
EP-5
EAST LAGOON
EP-1
SP-5
AUXILIARY LAGOON
PB-5
WP-1
PB-7
WP-5
Flow Recorder, Sta. 11
EP-4
WP-4
PB-8
PB-6
B.M. S.W. cor of conc. Outlet Box Elev. 2198.39
18" RCP Pipe
8" P Sewer
PB-4
2195
2190
2200
LEGEND
2200 Present Contours
2190 Original Contours
Sewer
½ Section Line
Fence
Property Line
B.M. Bench Mark (Datum
Santa Cruz River



LAGOON SITE

Figure 1.2

discharged through a pair of vertical ten-inch tees located at the third points of the narrow dimension and thirty feet from the north dike centerline. Effluent structures consist of an overflow conduit at the five-foot level opposite the inlet end and a valved emergency bottom discharge which empties to the east pond. At a depth of five feet, the exposed surface area is approximately two acres and the volume is approximately 3,300,000 gallons. The interior surface of the pond is unlined and no soil stabilization was attempted during compaction of either the pond bottom or the dikes.

1.3.2 Physiography

As indicated in Fig. 1.3, the ponds are located adjacent to (and approximately 20 feet above the riverbed) the Santa Cruz River, the head waters of which rise in the San Raphael Valley located in southeastern Arizona. The river meanders into Mexico, loops back across the international boundary, continuing north through Tucson and thence northwest to the Gila River near Phoenix, Arizona. Geology of the valley is typical of the basin and range provinces of the southwestern Unites States. Present relief is the result of block faulting occurring about the time of the last uplift of mountain formations in the Tertiary and early Quaternary periods. Following this uplift a long period of erosion was responsible for the deposition in the valley of great quantities of material. This pattern is typical in the southwest desert. The latest erosion period has been in recent geologic time and the present bottom land and flood plains are refill quantities in the inner valley.

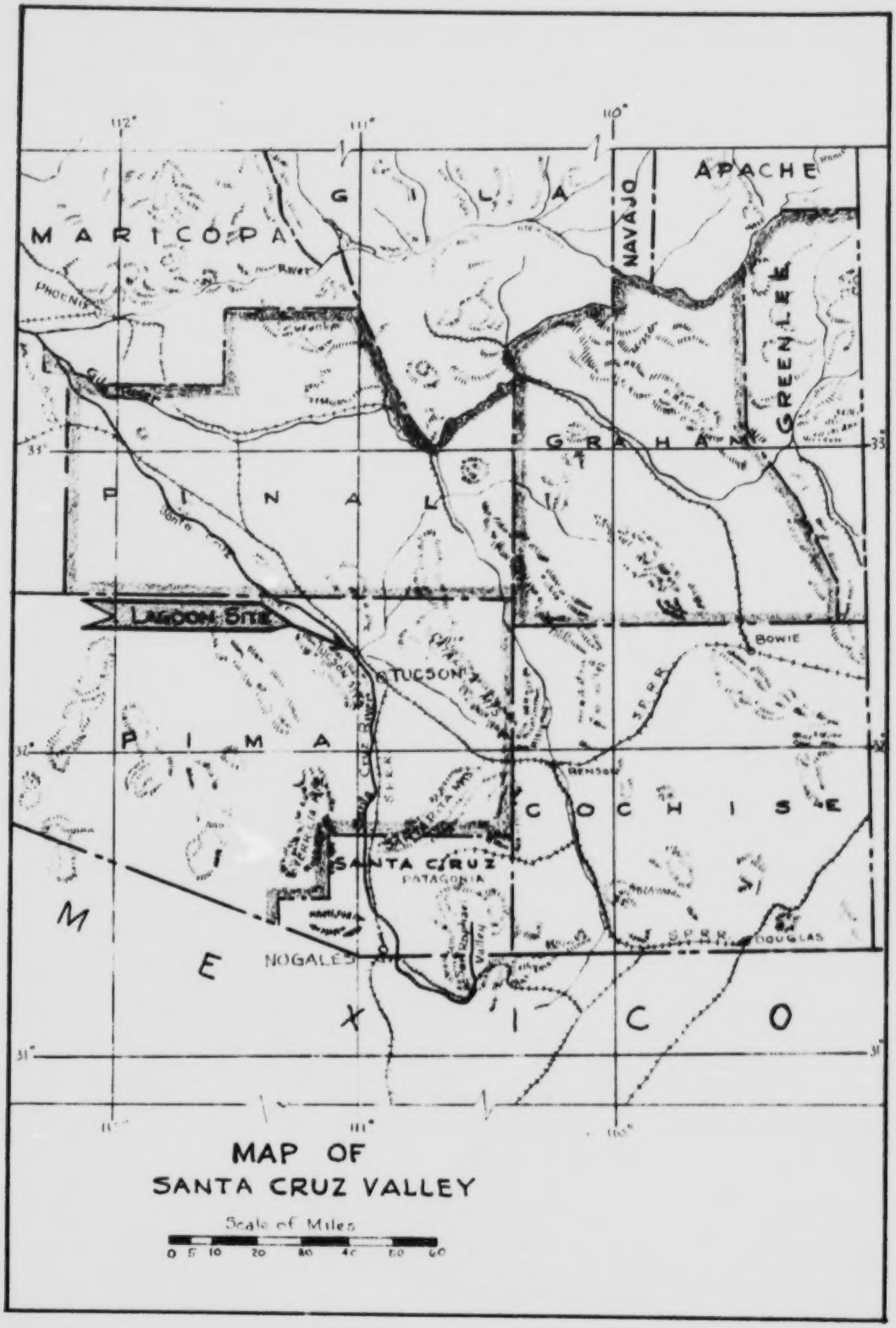

MARICOPA
GILA
APACHE
NAVAJO
GREENLEE
GRAHAM
PINAL
LAGOON SITE
TUCSON
BOWIE
PIMA
COCHISE
SANTA CRUZ
PATAGONIA
NOGALES
DOUGLAS
MEXICO
MAP OF
SANTA CRUZ VALLEY
Scale of Miles
0 5 10 20 30 40 50 60

Figure 1.3

1.3.3 Climatology

The climate of the area is classified as semi-arid with an average mean temperature in the vicinity of the lagoons of 67.4°F., and a long term average annual rainfall of 10.83 inches. The index of wetness, which is the ratio of the rainfall in a particular year to the average annual rainfall, varies from 0.48 to 2.2. This extreme variability of the index of wetness is characteristic of semi-arid and arid regions.

Rainfall in the area follows a pattern of winter and summer periods of precipitation. Winter rains, which generally occur during the months of December, January, and February, are the result of frontal activity or orographic uplift of Polar Pacific air masses. The storms generally move from west to east, and the resulting rains are normally of low intensity and may be of long duration. The moisture source of summer rains is air from the Gulf of Mexico which invades the southwestern United States in late June, July, and August. Updrafts caused by orographic lifting or thermal convection form thunderstorm cells. The resulting rain is typically of high intensity and short duration, and usually covers an area of less than 25 square miles.

Abundant sunshine and frequent breezes are characteristic of the region. The long term average percentage of possible sunshine is 86 per cent. Long term average maximum and minimum temperatures are 81.6°F. and 53.2°F. respectively. Representative values for maximum and minimum temperatures, percentage of possible sunshine, and average wind speed for the 1961-1962 study period are presented in Fig. 1.4.

CLIMATOLOGICAL DATA
TUCSON, ARIZONA

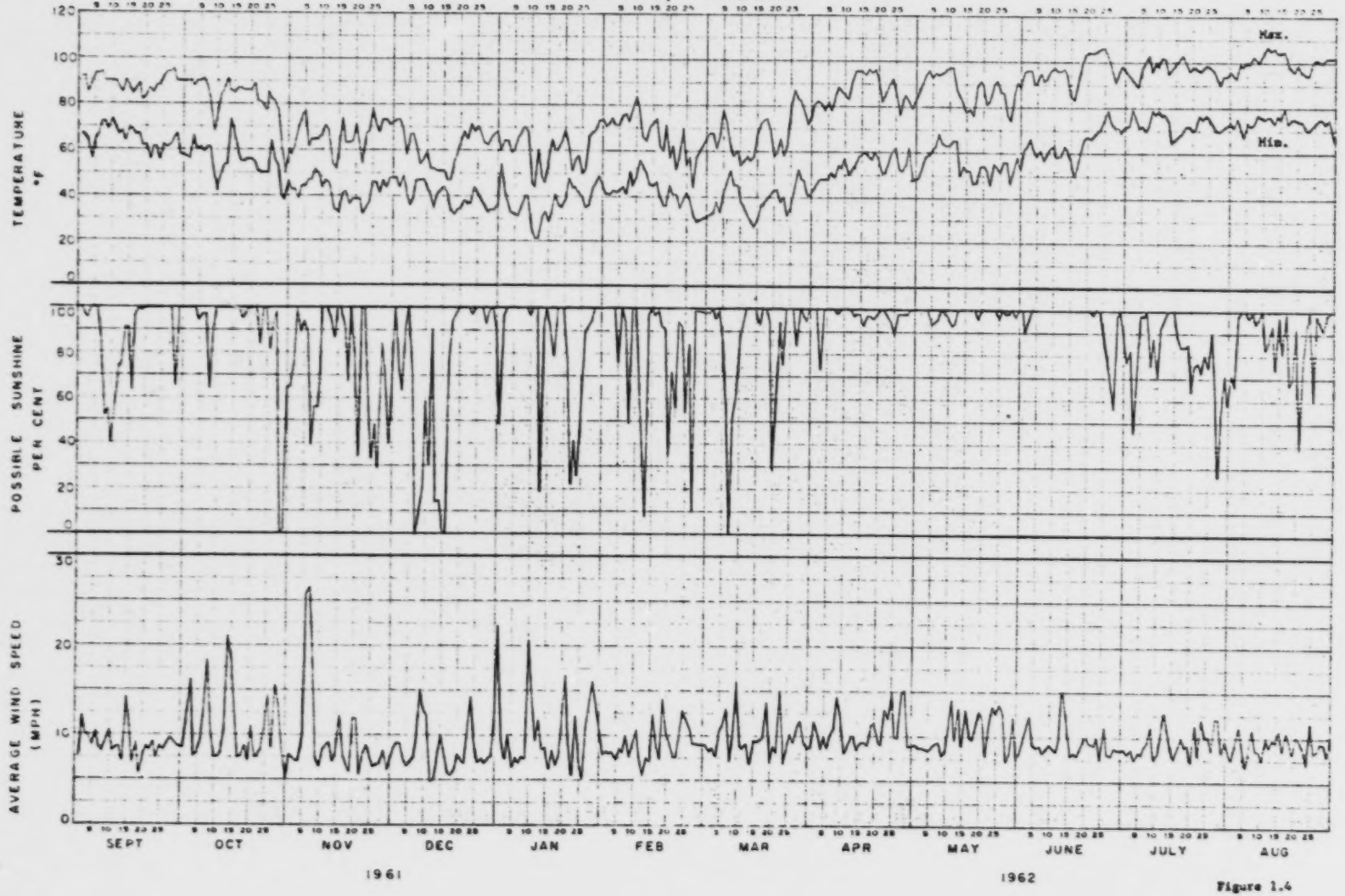


Figure 1.4

1.3.4 Vegetation

Adjacent to the lagoons, bottom lands are cultivated for agricultural purposes, while the riverbed and flood plain supports a few cottonwood trees and desert shrubs. The remaining non-agricultural land is covered with creosote bush, desert shrub, cacti, mesquite, and palo verde.

2. BIOLOGICAL INVESTIGATIONS

2.1 INCIDENCE OF PATHOGENS

The pathogens of interest in this study were Taenia saginata (beef tapeworm), Entamoeba histolytica (a parasitic intestinal amoeba of man), and Giardia lamblia (a parasitic intestinal flagellate of man). To obtain an idea of the prevalence of these parasites, the personnel of the major medical laboratories in this area were questioned. They were all of the same opinion -- that the parasitic protozoa listed, infected only a few per cent of the population. Also, they agreed that tapeworm infections are extremely rare in this area.

After approximately a year of contact with the local laboratories, only seven stools with E. histolytica and only one stool with T. saginata, a small worm with only a few mature proglottids, were obtained. During this time not a single stool containing Giardia lamblia was received.

Contact was made with the American University of Beirut in Lebanon and a medical laboratory in Nogales, Sonora, Mexico, as well as various laboratories in the United States(1), to obtain information on possible sources of T. saginata. In the U.S., the incidence of this parasite appears to be extremely low. None of the laboratories contacted could provide a supply of viable eggs. In Mexico and Lebanon, infections were more common, but obtaining specimens is just as difficult. It seems that most laymen do not consider T. saginata to be serious enough to warrant treatment(2).

Also, the people in these areas are reluctant to collect and return stools after treatment.

In addition to the survey of medical laboratories, a series of sampling stations was established in the vicinity of Tucson to determine the incidence of the eggs and cysts of the above organisms in the raw sewage. Samples were collected from sewers in both the lower and upper socio-economic areas, the Tucson Municipal Sewage Treatment Plant, and the influent to the stabilization pond. Samples from the sewers were collected on the average of once a month. One sample only was collected at the Tucson plant. The influent to the pond was sampled every eight days.

2.1.1 Evaluation of Techniques

A number of techniques were investigated as to their worth in detecting small numbers of eggs and cysts in large volumes of sewage. Direct smears of the samples and of the sediment of centrifuged samples proved to be of little value. The zinc sulfate centrifugal flotation method[3,4] was investigated. Wang found that this method was best for ascaris eggs; however, it was not very efficient for Entamoeba cysts. In this study, there were no cysts or eggs detected in the samples analyzed by the last method. From the standpoint of both the ease of manipulations and the efficiency of detection, best results were obtained using the formalin-ether method[5], and the aerosal-ether-xylene (AEX) method[6].

2.1.2 Results

No pathogens of interest were detected in samples taken from the sewers in the vicinity of Tucson or from the samples taken from the pond; however, intestinal protozoa were detected from the sludge of the primary treatment plant. Protozoan cysts were detected in the sludge by both the formalin-ether method and the AEX method.

Table 2.1 presents a comparison of the two methods:

Table 2.1

Method	Tube	ml Sludge	Entamoeba Cysts	Giardia Cysts	Cysts/ml (avg)
AEX	1	0.6	1		
	2	0.6	4		4.2
Formalin	3	10	10		
Ether	4	10	19	1	1.5

Most of the cysts were identified as E. Coli on the basis of the presence of eight nuclei; however, in a few, eight nuclei could not be detected. These were considered tentatively as E. histolytica. Positive identification was not possible on the unstrained material. The presence of Giardia in the Sample was interpreted as indicating that this flagellate is a common parasite in this area.

2.2 CULTURING AMOEBAE FROM STOOL SPECIMENS

2.2.1 General

As a result of the low incidence of all the parasites in question, it was decided to concentrate on E. histolytica, since this organism has been successfully cultured in the laboratory. Consequently, attempts were made to isolate this parasite from the stool specimens received.

2.2.2 Procedure

Five of the seven stools were received the same day that they were voided. The remaining two were received the following day. All stools were maintained at room temperature except one. This one specimen was over thirty hours old and had been in the refrigerator for about six hours. None of the stools were well formed and three were very liquid.

The culture medium used was Difco's liver infusion agar overlayed with 4 ml. of horse serum-saline (1:6) and with 2-3 loopfuls of sterile rice powder (Difco) added.

The cultures were innoculated in the following manner: a small pea-size bit of fecal material was planted into each of four tubes (15 by 150 mm.) of the above culture medium. The tubes were incubated at 37°C. and examined every day for eight days. However, after 48 hours, each tube was subcultured and each of these were examined for eight days before being discarded.

2.2.3 Results

Only two of the seven attempts to isolate E. histolytica from stools were successful. These successes came from the more solidly formed stools which contained considerable numbers of cysts. The more loose specimens contained predominately more trophozoites. The isolated trophozoites remained visible and active in the cultures for about five or six days. All attempts at subculturing were unsuccessful.

The above results are comparable to those found by others using the same medium[7]; that is, from stools known to contain cysts, only about 60 to 80 percent produced positive cultures.

2.3 CULTURING AMOEBAE FROM STOCK CULTURES

2.3.1 Entamoeba histolytica

Two strains of E. histolytica were used in this investigation:

1. Strain NIH-200. This strain was obtained from the Communicable Disease Center, Phoenix Field Station, Phoenix, Arizona, through the courtesy of Dr. F. O. Atchley.

2. Strain NRS, a monkey strain originally isolated by Mr. C. Dobell of London. This strain was secured through the cooperation of Dr. L. Jacobs of the National Institutes of Health, Bethesda, Maryland.

2.3.2 Media

2.3.2.1 Cleveland's Liver Infusion Agar Medium, Modified[8]

Thirty-three grams of Difco Bacto-Entamoeba medium power were boiled in a liter of distilled water for a few minutes. The solution was dispensed while hot into each of a batch of culture tubes (15 x 150 mm.) and autoclaved at 15 lbs. pressure for 20 minutes in a slanting position. The tubes were cooled and left at room temperature for one or two days to allow the slants to stiffen. Slants were then covered with 4 ml. of a sterile M/30 phosphate-salt solution, buffered at a pH of 8.0, to which had been added horse serum in the ratio of 10:1. Before using, 2 to 3 loopfuls of sterile rice powder were added.

2.3.2.2 Modified Boeck and Drbohlav's Medium[9]

Fresh eggs washed with soap and water and rinsed with 70 percent alcohol were homogenized in a Waring blender with 50 cc. of sterile Locke's solution for each 180 cc. of egg. The mixture was dispensed into tubes to make a slant of about 1 1/2 inches (4-5 cc.). Then the tubes were placed in a slanting position in the autoclave and inspissated for 15 minutes at 15 lbs. After the

inspissated slants were cold, sterile Locke's solution was added to cover the slants to a depth of about 1 cm. The medium was then sterilized at 121°C. (15 lbs.) for 15 minutes. The medium was tested for sterility by incubating at 37°C. for 24 hours. Sterile rice powder (2-3 loopfuls) was added just before using the tubes.

2.3.2.3 Chang's Encystment Medium[8]

To 20 ml. of sterile phosphate-salt solution (M/30 phosphate in 0.4 percent NaCl solution), buffered at a pH of 7.6, was added 1/5 ml. of sterile liver extract (No. 343, Lilly Company product). The medium was dispensed into sterile tubes, 15-20 ml. each. Then sterile rice powder was added -- 2-3 loopfuls -- and the tubes were incubated for 24 hours at 37°C. to check for sterility. The tubed media was stored in the refrigerator until used.

2.3.3 Results

2.3.3.1 General

Although the amoebae grew abundantly in both the liver and egg media, there were times when the cultures tended to deteriorate. This was especially noticeable with the liver medium. The cultures would become progressively poorer and finally die out. Sometimes the culture could be saved by washing the amoebae in sterile saline and planting the washed amoebae into fresh culture tubes innoculated with NRS bacteria from a healthy culture. It would appear that the bacterial flora had become unfavorable for the growth of the amoebae.

The two strains used were quite different in their response to attempts at encystment. Although a considerable number of attempts were made, the NIH-200 strain could not be induced to

encyst. Both the egg and the liver methods were tried with no success. After the NRS strain was obtained, the NIH-200 was dropped. Cysts could be obtained from this second strain, but not in the numbers anticipated or needed. However, only the egg medium produced encystment in this strain. After many trials, the liver method was abandoned in favor of the egg.

2.3.3.2 Time of Encystment

A number of experiments were performed with the NRS strain in egg media to determine the time at which the maximum encystment takes place. After depriving the amoebae of rice powder for eight days, they were transferred into cultures containing rice. Growth for the first 24 hours was quite slow. In the next 24 hours, the amoebae began to divide rapidly, increasing tremendously in numbers. It was at this time, approximately 48 hours, that the maximum number of cysts appeared. The cysts soon began to disappear indicating, perhaps, that they were excystating. Table 2.2 presents these results.

Table 2.2 Time of Encystment

Trial	Culture Age in Hours			
	24	36	48	60
1	0	0	+	0
2	0	0	+++	+
3	0	0	+	0
4	0	0	0	0
5	0	0	++	+
6	0	0	0	0
7	0	0	0	0
8	0	0	+	0

0 = no cysts observed ++ = 1-5 percent encysted

+ = less than 1 percent encysted +++ = 5-10 percent encysted

2.3.3.3 Number of Cysts

To determine the number of cysts that could produced by the method used, the following procedure was followed: The pooled sediment from four 48 hour encystment cultures was washed with sterile saline until the supernatant was clear. Then the saline was replaced with distilled water and the suspension diluted to 5 cc. The diluted suspension was stored in the cold box for 24 hours.

Since Chang[10] found that cyst counts made with a hemocystometer gave results 20 percent or more too high, owing to the fact that cysts settle rapidly on the counting stage, the drop count method also described by Chang was used to obtain the concentrations of the cysts in the above suspensions. To obtain the count, five drops of the suspension were taken at various levels and placed separately on microslides. The cysts in each drop were counted and the average for each suspension was calculated. This average multiplied by the number of drops per cc. was used as the number of cysts per cubic centimeter.

From Table 2.3, it is seen that the number of cysts per tube varied from 50 to 700 with an average of 257.5. These figures do not represent the number of cysts available for experiments as they include both mature and immature cysts. It was estimated that from 10 to 20 percent of the cysts were immature.

2.3.3.4 Excystment

In each case the cyst suspensions, after remaining in the refrigerator for 24 hours, were planted into fresh media to check

Table 2.3 Cyst Count

Suspension No.	No. of Cysts (Avg. of 5 drops)	No. of Cysts Per Tube	Excystment
1	7	175	+
2	28	700	+
3	2	50	
4	11	275	+
5	16	400	+
6	2	50	
7	3	75	
8	5	125	
9	21	525	+
10	8	200	+
Avg.	10.3	257.5	

on viability. The cysts were resuspended and a drop of the suspension was planted into two tubes each of both egg and liver medium. These were incubated at 37°C. and examined on the second day. If negative for amoebae on the second day, the tubes were examined on successive days until at least the seventh day before being discarded as negative. All the suspensions that contained 7 or more cysts per drop, on the average, excysted in both media after 24 hours in the refrigerator (Table 2.3).

In anticipation of introducing cysts into the pond, an experiment was conducted to determine whether it would be possible to get excystation after the amoebae were exposed to pond water. Since the pond water is heavily laden with material such as algae, bacteria, suspended solids, and dissolved inorganic and organic salts, it was deemed important to evaluate the effect of this debris on excystation.

Cyst suspension number 9 was centrifuged; the supernatant was drawn off and replaced with pond water. The cysts were

resuspended and one drop was planted into each of 4 tubes of both liver and egg medium. No attempt was made to wash the cysts or separate them from the suspended material. From these eight tubes only one, containing liver medium, produced a positive culture (Table 2.4). This was considered as a positive indication that the pond water was not completely detrimental to excystation.

Table 2.4 Excystment in Pond Water

Tube Number	Media	Excystment
1	Liver	-
2	Liver	+
3	Liver	-
4	Liver	-
5	Egg	-
6	Egg	-
7	Egg	-
8	Egg	-

3. PHYSICAL FACTORS INFLUENCING RETENTION OF PATHOGENS

3.1 INTRODUCTION

Once particulate matter has entered a detention basin of the type under study, the most obvious routes of escape are in the effluent flow or by infiltration. There is, of course, the remote possibility that material from the basin could be carried some distance by high winds. The health significance of escape of viable pathogens in the effluent or by infiltration into the containing soil and thence into the water table is obvious.

3.2 ESCAPE BY EFFLUENT FLOW

3.2.1 General

Evaporation rates in the semi-arid southwest have been found to be of such magnitude that the possibility of effluent flow in certain installations is eliminated. Some installations have actually been designed with no provision for taking care of flow from the basin.

The absence of an effluent has been observed to be quite common during the early periods of operation. It was approximately 18 months before the study pond produced a measurable outflow. However, the quantity of effluent has increased steadily since the installation was completed, and, presently, the effluent flow accounts for the majority of liquid loss from the pond. Since self-sealing has probably retarted the infiltration rate, it would seem reasonable to conclude that the effluent flow provides the most obvious route for particulate escape. The subjects of self-sealing and evaporation will be taken up in more detail later in the report.

3.2.2 Theoretical Retention Time

Biochemical Oxygen Demand and retention time have been recognized as important parameters in evaluating the effectiveness of treatment by sewage stabilization ponds. In recognition of the importance of retention time, the Arizona State Department of Health has set up, as a design criterion, a minimum retention time of 30 days. Theoretical average retention times for the study pond for various periods are presented in Table 3.1. The average daily flow for each period was computed from continuous gauge height records, and this figure was then divided into the volume of the pond to yield the retention period.

Table 3.1

THEORETICAL RETENTION TIMES

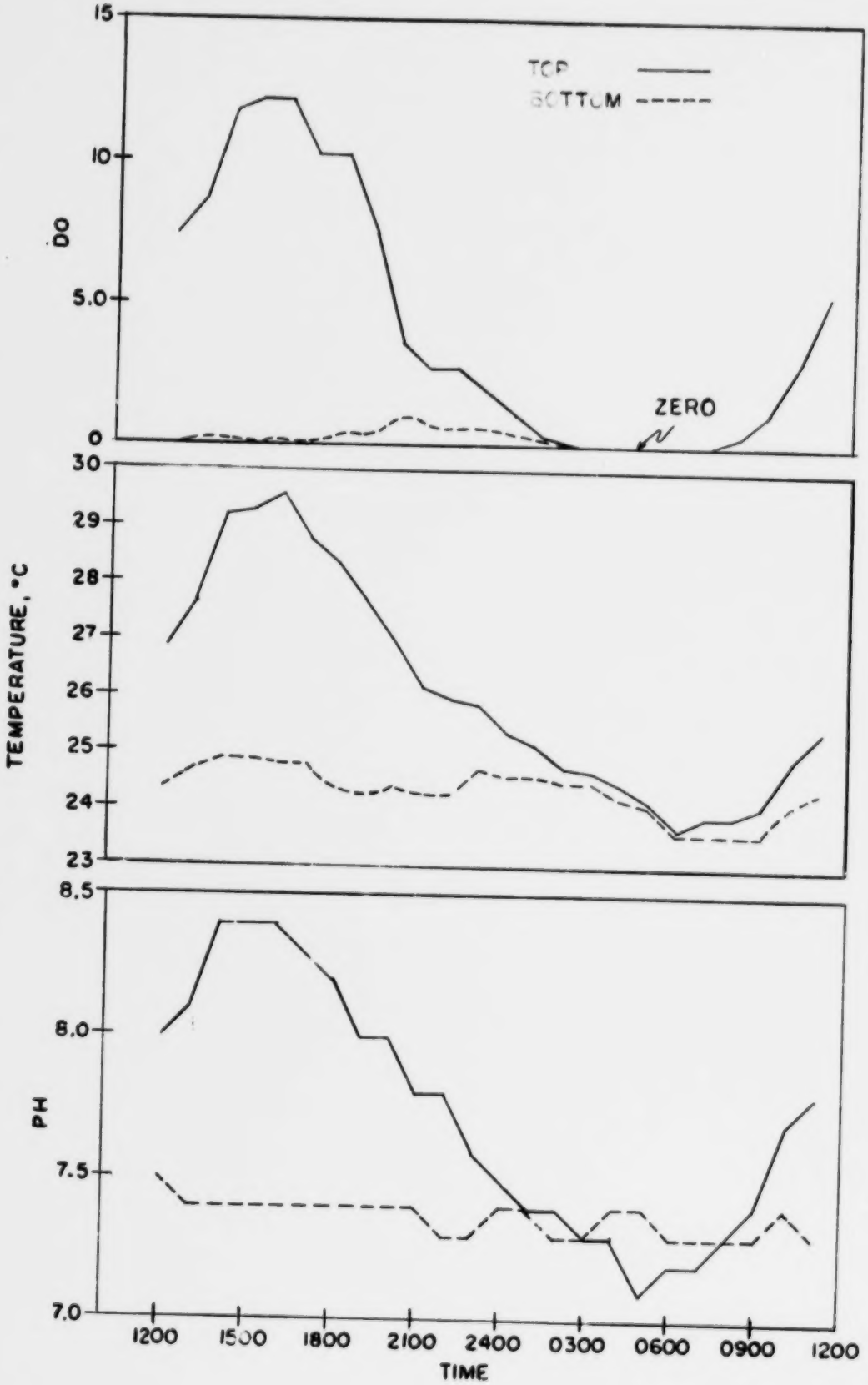
Dates (Inclusive)	Average Influent (Cu. Ft./Day)	Average Retention Time (Days)
March 10-13, 1962	8,370	48
March 27-31, 1962	10,120	40
April 1-16, 1962	9,980	40
May 17-29, 1962	12,810	31
June 2-7, 1962	13,580	30
July 20-30, 1962	13,910	29
August 24-28, 1962	13,920	29

3.2.3 Factors Affecting Theoretical Retention Time

It has been demonstrated by numerous investigators that many factors influence effective retention time in basins designed to re-

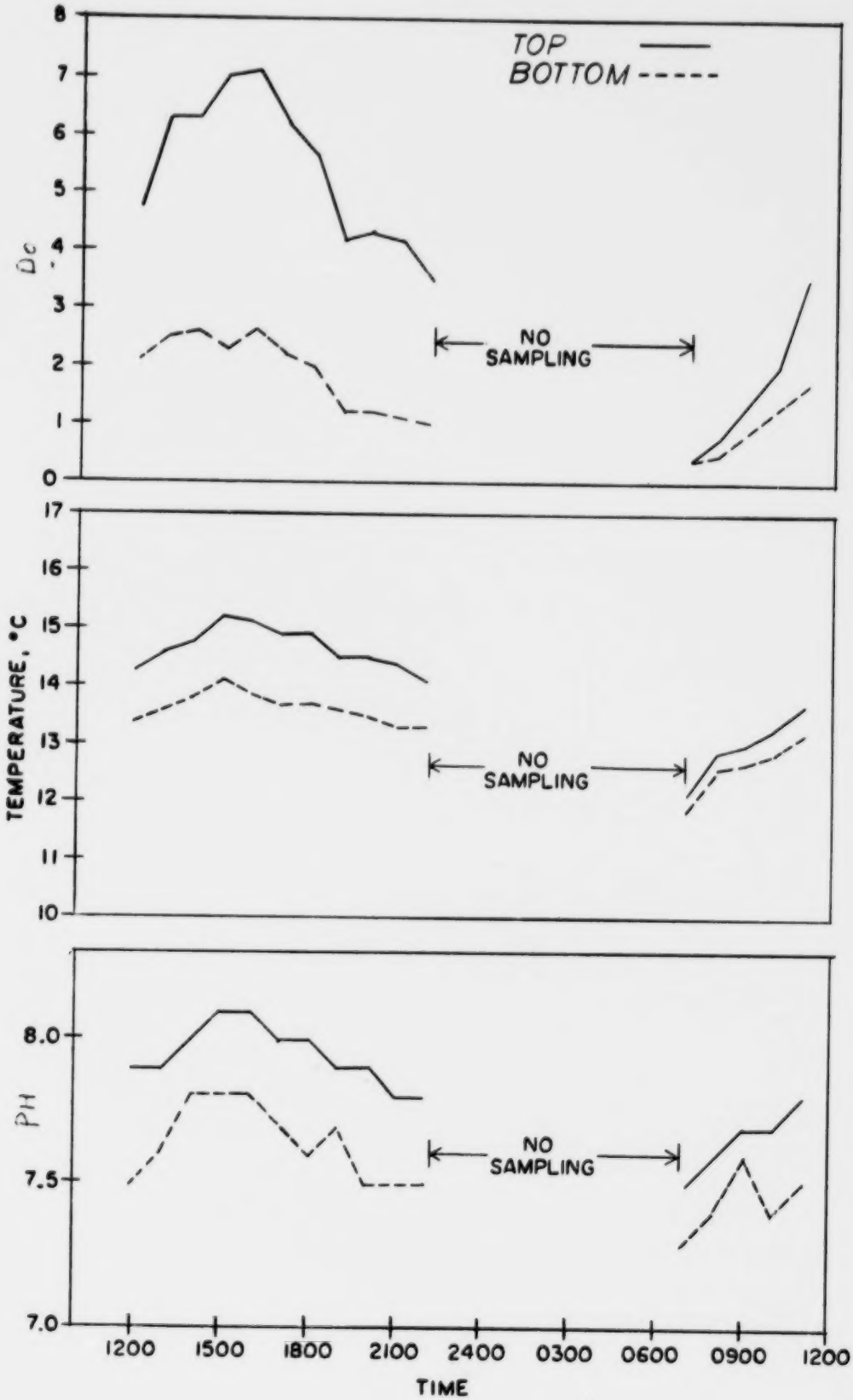
tain sewage flow. Short circuiting, due to temperature stratification, is probably one of the more significant of these factors. In an effort to evaluate the temperature parameter in the study pond, temperature, dissolved oxygen, and pH data accumulated during the months of June and July 1962, was analyzed. Figures 3.1 and 3.2 present the average composite hourly values for temperature, dissolved oxygen, and pH recorded for top and bottom samples accumulated during seven sampling periods of 24 hours each. It should be significant to note that the temperature differential reached a maximum value of 4.5 degrees centigrade during the afternoon hours. Further examination of Figure 3.1 indicates that corresponding differentials existed during the same period for dissolved oxygen and pH. Observed simultaneous reductions in the three differentials would seem to indicate that mixing resulting from temperature change could account, at least in part, for the reduction in dissolved oxygen and pH differentials recorded. A tracer study conducted on August 10, 1962, seemed to substantiate this observation (see Section 4.4.)

Limnologists have long been aware that the effect of wind action on a body of water is largely dependent upon temperature stratification. If no temperature stratification exists, then a slight wind will cause extensive water movement and mixing. On the other hand, it has been noted that very little temperature stratification is required to observe wind-induced cellular effects. These effects may be in the form of circulation induced by the wind in a shallow layer of water with no movement observed in deeper layers. Of course, as the ratio of surface area to depth increases, wind action becomes more effective in mixing.



AVERAGE HOURLY DO, PH, AND TEMPERATURE VALUES
6/11/62 — 7/30/62

FIG. 3.1



AVERAGE HOURLY DO, PH, AND TEMPERATURE VALUES
10/12/61 – 5/11/62

FIG. 3.2

Gas production resulting from anaerobic action in the benthal layer has been noted to cause localized water movement. Excessive gas production of this type is undesirable since offensive odors may result. In the study pond, gas production of this magnitude was observed to occur predominantly during periods of extended overcast and/or overloading. The degree to which gas production might affect stratification is problematical. Since lower air temperatures accompanied periods of overcast, the observed decreased temperature differentials during these periods could not be directly attributable to increased gas production in the bethal layer. It was noted, however, that stratification at these times was not as marked as during sunny periods.

During the June 27-28, 1962, sampling period, an intense rain began at approximately 1800 and lasted a little over two hours. Subsequent analysis of the data taken during this period illustrated the rather dramatic effect which high winds and precipitation can exert upon temperature and pH. Although sampling was halted, as a precautionary measure, during the duration of the storm, Figures 3.3 and 3.4 illustrate how rapidly top and bottom temperatures were equalized. Figures 3.5 and 3.6 indicate that a similar equalization of pH took place during the same time period. During the most intense period of the storm, it was observed that wind-induced waves were of sufficient height to carry pond water for a considerable distance over the 3-foot embankment or freeboard. It should be of interest to note that during this period of high wind and rain the third means of pathogen escape became a reality.

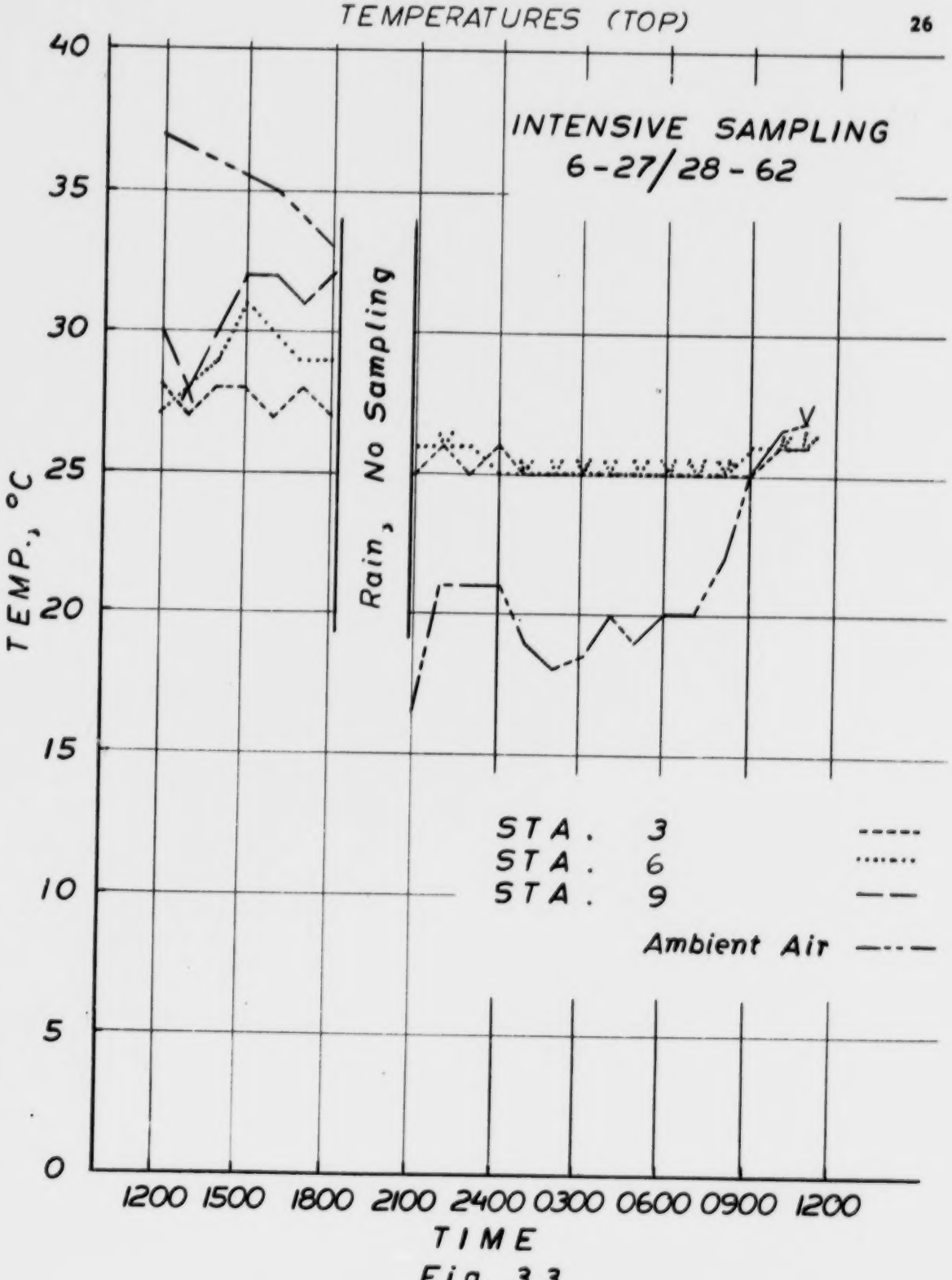

TEMPERATURES (TOP)
INTENSIVE SAMPLING
6-27/28-62
Rain, No Sampling
TEMP., °C
40
35
30
25
20
15
10
5
0
STA. 3
STA. 6
STA. 9
Ambient Air
1200 1500 1800 2100 2400 0300 0600 0900 1200
TIME

Fig. 3.3

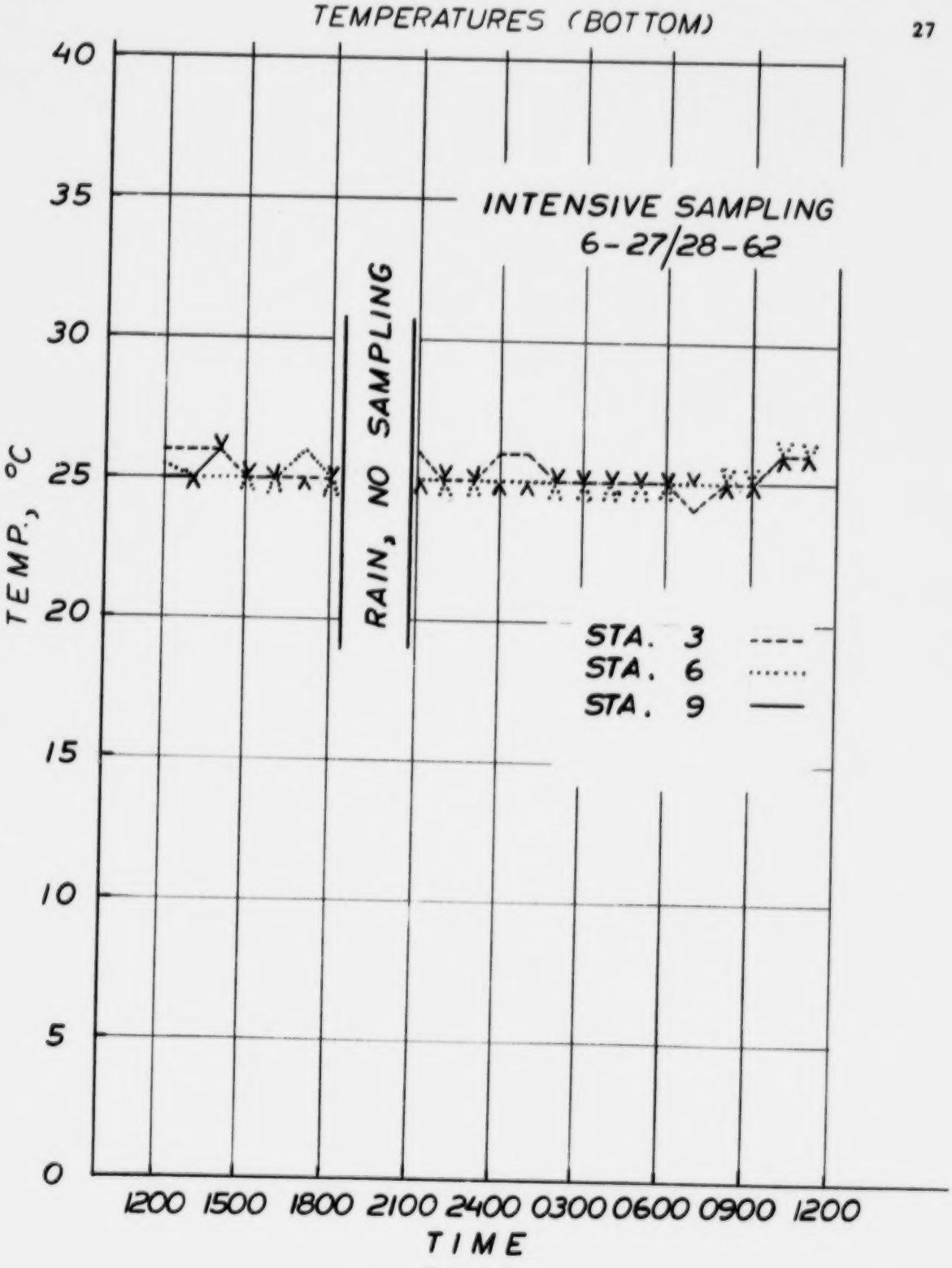

TEMPERATURES (BOTTOM)
INTENSIVE SAMPLING
6-27/28-62
RAIN, NO SAMPLING
STA. 3
STA. 6
STA. 9
TEMP., °C
40
35
30
25
20
15
10
5
0
1200 1500 1800 2100 2400 0300 0600 0900 1200
TIME

Fig. 3.4

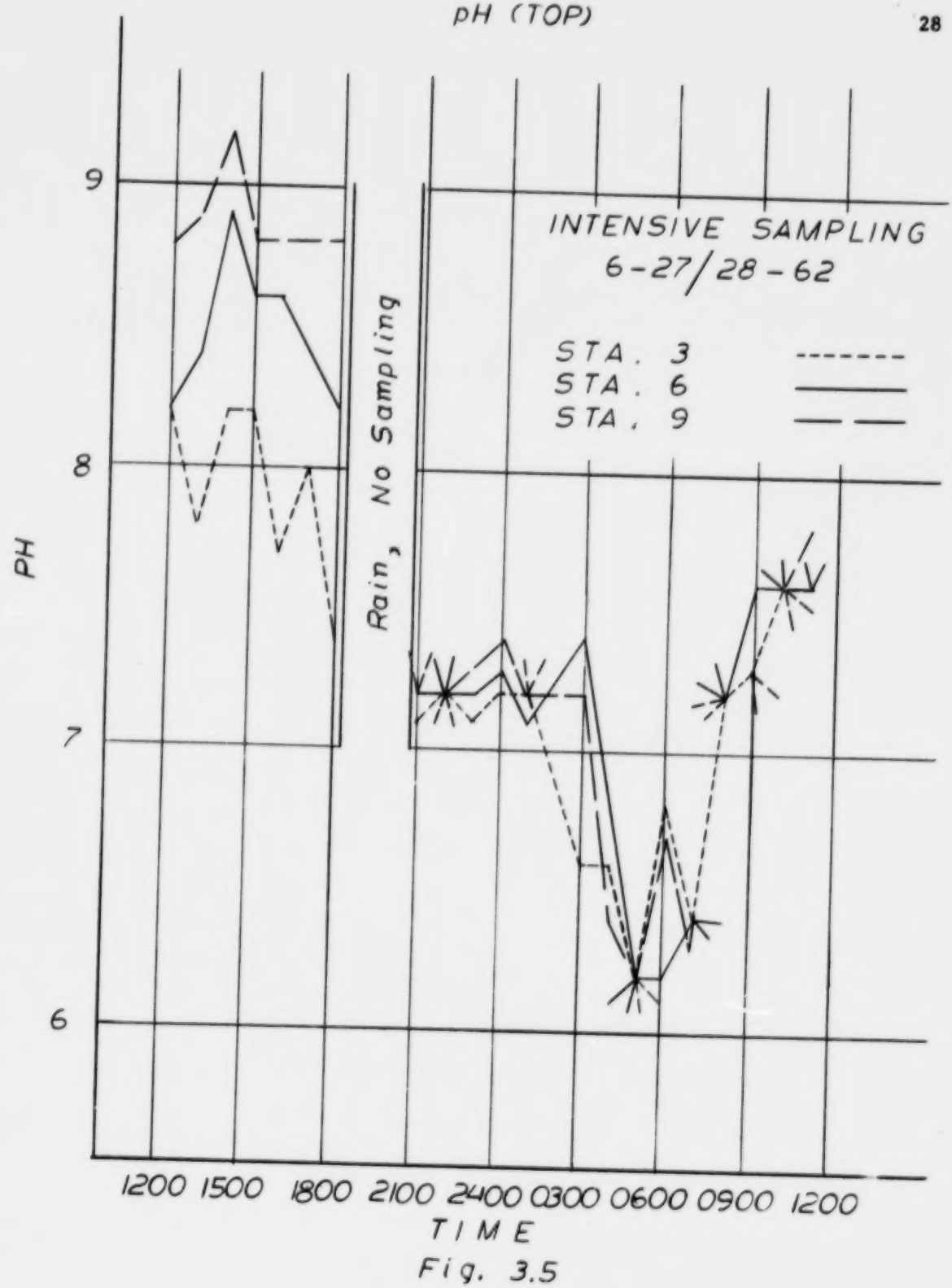

pH (TOP)
INTENSIVE SAMPLING
6-27/28-62
STA. 3
STA. 6
STA. 9
Rain, No Sampling
PH
9
8
7
6
1200 1500 1800 2100 2400 0300 0600 0900 1200
TIME

Fig. 3.5

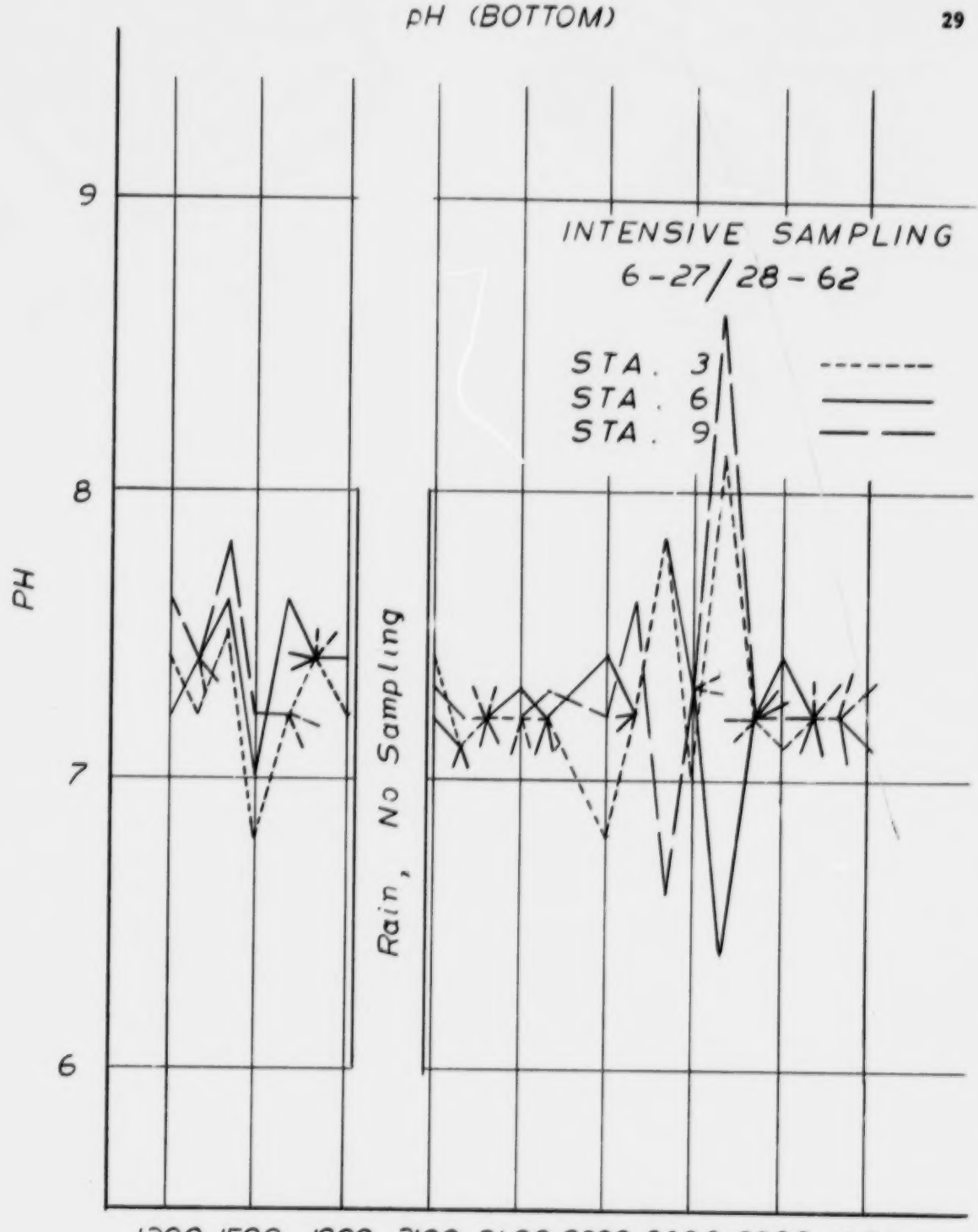

pH (BOTTOM)
INTENSIVE SAMPLING
6-27/28-62
STA. 3
STA. 6
STA. 9
9
8
7
6
PH
Rain, No Sampling
1200 1500 1800 2100 2400 0300 0600 0900 1200
TIME

Fig. 3.6

3.2.4 Intrinsic Factors

Although exhaustive studies of stratification and effective retention time are possible, certain intrinsic factors associated with the pathogens in question are probably responsible for the numerous difficulties encountered in efforts to delineate the true route of pathogens through sewage stabilization ponds.

A number of investigators have observed the failure of the sedimentation process in removing E. histolytica cysts from sewage with conventional treatment. Gordon[11] failed to remove all of the cysts from the effluent of Moscow sewage after storage in a tank for 6.5 hours. Cram[12] found no evidence for settling at a depth of 6.5 and 26 inches in storage tanks after a period of three hours. Chang[13] calculated that it would take about 6 hours for cysts to settle through 6.5 inches of fluid of the density of water at 25 to 28° C. Also, using Stoke's law and the observed settling rate of the cysts in distilled water, he calculated the specific gravity to be 1.060.

Taenia saginata eggs are several times larger than the amoeba cysts, and therefore their rate of settling would be considerably greater. Newton[14] observed the following settling rates for T. saginata eggs: 65% of the eggs settled at 0.6 inches per minute; 16% of the eggs settled at 0.3 to 0.6 inches per minutes; and 17% of the eggs settled at 0.15 to 0.3 inches per minute. These rates were determined in 18 inch columns of raw sewage. He concluded that with moderate overflow and 1-2 hours of detention time, sedimentation would remove the majority of eggs. However, a significant number would escape in the effluent.

Since the average depth of the pond is approximately 5 feet, using the settling rate for amoeba cysts calculated by Chang, a detention time of approximately 2 days would be required to settle all of the cysts. The detention time required to settle all of the tapeworm eggs, using Newton's datum of 0.15 inches per minutes, would be approximately 6.5 hours.

3.3 INFLITRATION

3.3.1 General

Previous investigations have indicated that infiltration through permeable soils may be an important contributing factor in contamination of underground water supplies. Fuller and McClintock[15] invited attention to broad irrigation procedures, which allowed percolation of sewage water through the soil horizons. It was the opinion of these investigators that the adoption of such procedures could lead to the transmission of pathogenic organisms and the pollution of underground aquifers. Steel[16] advised that the ideal soil for stabilization pond construction should be relatively impervious so there would not be excessive seepage. He further stated, however, that some pervious soils seal up within a short time. Neil and Hopkins[17] reporting an experimental lagoon built up on gravel and sand stratums near Kearney, Nebraska, found seepage followed a course that showed up in wells nearby. Since natural sealing resulting from the accumulation of sewage solds did not materialize, the investigators recommended impermeabilization or relocation of the lagoons in order to protect the groundwater from seepage. A joint report of investigations conducted in the Dakotas[18] stated that seepage should be a factor considered in the design of

stabilization lagoons. The American Society of Civil Engineers, Manual No. 36[19], directs attention to consideration of porosity of pond bottoms and advises that in several instances pond bottoms have been sealed. Jaffe[20] related there was some speculation about the possibility of ground water contamination by percolation of lagoon water. He advised that this possibility be investigated before sewage lagooning was adopted for waste treatment. Meinzer[21] emphasized the fact that principals controlling leakage are the same as those controlling natural flow of groundwater. He stated that leakage varies according to the character of the material and, in the process, water moves into the interstices of the containing soil increments and fills them. In some cases leakage may be gradually diminished by saturation of the underlying stratums, thus building up the zone of saturation.

It was in recognition of the significance of potential contamination by infiltration that an investigation of the self-sealing potential of the pond under investigation was initiated. The plan for conducting this investigation was based upon the hydrologic equation. This equation is one of hydrologic equilibrium and is stated quantitatively as follows:

Influent = Evaporation loss + Seepage loss + Effluent.

3.3.2 Flow Measurements

Flow into and out of the west lagoon was recorded by means of two Steven's Stage Recorders installed in conjunction with Palmer-Bowlus flumes. The stage recorders provided a continuous record of the fluctuating depths of flow in both the influent and effluent pipes. Recorded stage data served as the basis for determining the

head on the Palmer-Bowlus flumes. Once this information was obtained, discharge computations were made using standard curves for the influent and effluent flumes. Although intermittent and unpredictable fouling of the flume mechanism prevented the accumulation of continuous long-term stage records, it was felt that representative periods of record during June, July, and August, 1962, were accumulated. These data are presented in Tables 3.2, 3.3, 3.4, and 3.5. It should be noted that information for the east lagoon is also included in these tables.

3.3.3 Evaporation

The determination of evaporation rates required an indirect procedure, since it was not feasible to measure evaporation from the lagoon surface directly. Actual evaporation measurements were made in a Standard Class A, U. S. Weather Bureau, land pan. These data were compared to similar data taken at two separate locations within a radius of 8 miles of the study site (see Figure 1.1). The comparative data were taken by representatives of the Solar Institute and the Institute of Water Utilization. Two straight line regression equations were developed by comparing the data accumulated by the two institutes with that accumulated at the pond site. The equations considered most applicable to the period under consideration are indicated in Tables 3.2, 3.3, 3.4, and 3.5 which include influent, effluent, seepage, and evaporation data.

3.3.4 Seepage

Prior to construction of the lagoons, soil samples were taken from the proposed construction site and standard tests were performed to determine the coefficient of permeability of the soil at a specified

RESUME OF LOSSES FROM WEST VAN SEWAGE STABILIZATION LAGOON

Date	1 * Pan Evaporation X Inches	2 * Lagoon Evaporation Y Inches	3 Lagoon Evaporation 2 / 12* Feet	4 Total Evaporation 3 x 86700 cu.ft./Day	5 ** Seepage (bottom) Cf./Day	6 # Seepage (Slope) Cf./Day	7 Total Loss 4+5+6 Cu.Ft./Day	8 Influent Sta.1 Cu.Ft./Day	9 Effluent Sta. 11 Q_R Cu.Ft./Day	10 Calculated Effluent Sta. 11 8-7 Cu.Ft./Day
6-2-62	0.15	0.09	0.008	694	890	570	2150	14484	11861	12553
6-3-62	0.43	0.26	0.02[illegible]	1910	890	570	3370	13834	11371	10340
6-4-62	0.54	0.33	0.027	2340	890	570	3800	14106	11390	10310
6-5-62	0.42	0.26	0.022	1910	890	570	3370	12783	11333	9590
6-6-62	0.40	0.25	0.021	1820	890	570	3270	12484	12084	9370
6-7-62	0.39	0.23	0.019	1649	890	570	3110	13583	12484	10470
									70860	62910

* Evaporation Data from the Solar Energy Institute

and Conversion equation Y = 0.567 + 0.0134

$$\frac{Q_R - Q_E}{Q_R} = \frac{(70660 - 62910)}{70660} \times 100 = 10.9\%$$

** Value from Column 5, Table 3.3

Value from Column 6, Table 3.3

RESUME LOSSES FROM WEST LAGOON AND A SUMMATION OF THE EAST AND WEST LAGOONS

Date	1 Y Lagoon Evaporation Feet	2 **** Total Evaporation 1 x 79000 Cu.Ft./Day	3 **** Seepage (Bottom) Cf./Day	4 *** Seepage (Slope) Cf./Day	5 Total Loss 2+3+4 Cf./Day	6 Total Loss # Cu.Ft./Day	7 Total Loss Lagoons 5+6 Cu.Ft./Day	8 Effluent Sta. 12 Gal. Per Min.	9 Effluent ## Cf./Day	10 Calculated Total Effluent 7+9 Cu.Ft./Day	11 Influent Sta.1 ### Cu.Ft./Day
6-2-62	0.008	630	2350	900	3880	2150	6030	24.3	4610	10640	14480
6-3-62	0.024	1740	2350	900	4990	3370	8360	23.5	4610	12970	13850
6-4-62	0.027	2130	2350	900	5380	3800	9180	23.2	4420	13800	14110
6-5-62	0.022	1740	2350	900	4990	3370	8360	24.3	4610	12970	12780
6-6-62	0.021	1660	2350	900	4910	3270	8180	27.7	5420	13600	12480
6-7-62	0.019	1510	2350	900	4760	3110	7870	26.7	5210	13080	13560
										76960	81460

**** Value From Column 3, Table 3.4

*** Value From Column 4, Table 3.4

f From Column 3 Above

$(Q_R - Q_E) / Q_R = (81460 - 76860)/81460 = 0.0564$ or 5.64%

Total Loss Values from Column 7 - West Lagoon ### from Column 8 Above

Column = Column 8 x 1440 ÷ 7.5

Table 3.2

SCOPE OF [illegible] ... PAN [illegible] STABILIZATION LAGOON

Date	1 • Pan Evaporation Inches	2 • Lagoon Evaporation Inches	3 Lagoon Evaporation 2 / 12" Feet	4 Total Evaporation 3 x 9x700 Cu.Ft./ Day	5 •• Seepage (Section) Cu.Ft./Day	6 Seepage (Loss) Cu.Ft./Day	7 Total Loss (4+5+6) Cu. Ft./ Day	8 Influent Total Cu.Ft./Day	9 Effluent Eqn. 11 Cu.Ft./Day	10 Calculated Effluent Eqn. 12 & 7 Cu.Ft./Day
7-[illegible]-56	0.315	0.1971	0.0164	1430	490	570	2490	13950	11340	10470
7-[illegible]-57	0.[illegible]69	0.1895	0.0158	1370	-	-	2530	13740	11[illegible]0	11[illegible]0
7-12-58	0.[illegible]08	0.0769	0.0256	2220	-	-	3660	14170	10810	7410
7-[illegible]-[illegible]	0.[illegible]75	0.[illegible]335	0.0195	1690	-	-	3130	13640	11730	11410
7-14-[illegible]	0.[illegible]55	0.[illegible]69	0.0317	2750	-	-	4110	13[illegible]0	1[illegible]0	[illegible]10
7-[illegible]-[illegible]	[illegible].[illegible]07	0.[illegible]13	0.[illegible]26	2220	-	-	3610	13840	11[illegible]0	81[illegible]0
7-16-[illegible]	[illegible].85	0.[illegible]69	0.0317	2750	-	-	4110	14670	11[illegible]0	10[illegible]8
7-17-[illegible]	[illegible].[illegible]30	0.0838	0.0069	600	-	-	[illegible]60	14[illegible]0	13570	12[illegible]7
7-18-[illegible]	0.[illegible]75	0.[illegible]30	0.0195	1690	-	-	3150	1 240	11[illegible]0	[illegible]90
7-19-62	0.250	0.1801	0.0135	1150	-	-	2610	16783	13540	14170
7-[illegible]-[illegible]	0.[illegible]93	0.[illegible]12	0.0239	1960	-	-	3120	14220	11[illegible]2	10[illegible]3
									1.[illegible]70	117[illegible]

• Evaporation as Lagoon: Y = 0.[illegible]X + 0.[illegible]

$$\text{Var}(e_i) = \frac{(1.[illegible]37^2 + 117[illegible]1)}{1[illegible]7^2} \times 10.[illegible] = 1.[illegible]\%$$

•• Seepage through the side slopes of the west lagoon

$$Q = Ak_1 i = \frac{\text{Area}}{\text{Side Slopes}} \frac{\text{Permeability}}{\text{Foot-Depth}} \frac{\text{Gradient}}{\text{Head ÷ Distance over which it is Lost}}$$

$$Q = Ak_1 i = 14370 \times 0.004[illegible] \times \frac{7.5'}{3''/1.''} = 570 \text{ cu.ft. per day}$$

••• Seepage through the bottom of west lagoon

$$Q = Ak_1 i = \frac{\text{Area}}{\text{Bottom}} \frac{\text{Permeability}}{\text{Coefficient for slime blanket}} \frac{\text{Gradient}}{\text{Head ÷ Distance over which it is Lost}}$$

$$Q = Ak_1 i = 74500 \times 0.0.12 \times 5'/(6'' \div 1.'')$$

$$= \text{[illegible]90 cu.ft. per day}$$

Table 3.3

SCHEME OF LAGOON FOR ... RAW SEWAGE STABILIZATION

Date	1 * Pan Evaporation X Inches	2 * Lagoon Evaporation Y Inches	3 Lagoon Evaporation 2 / 12" Feet	4 Total Evaporation 3 x 86700 Cu.Ft./ Day	5 ** Seepage (Bottom) C.F./Day	6 # Seepage (Slope) C.F./Day	7 Total Cu.Ft./
7-20-62	0.313	0.1971	0.0165	1430	890	570	289
7-21-62	0.300	0.1895	0.0158	1370	"	"	255
7-22-62	0.300	0.3069	0.0256	2220	"	"	356
7-23-62	0.375	0.2335	0.0195	1690	"	"	315
7-24-62	0.625	0.3669	0.0317	2750	"	"	421
7-25-62	0.500	0.3069	0.0256	2220	"	"	369
7-26-62	0.625	0.3669	0.0317	2750	"	"	421
7-27-62	0.130	0.0838	0.0069	600	"	"	206
7-28-62	0.375	0.2335	0.0195	1690	"	"	315
7-29-62	0.250	0.1601	0.0133	1150	"	"	261
7-30-62	0.463	0.2852	0.0238	1960	"	"	342

* Evaporation on Lagoon: Y = 0.587X + 0.0134

\# Seepage through the side slopes of the west lagoon

$$Q = Aki = \frac{\text{Area}}{\text{Side Slopes}} \quad \frac{\text{Permeability}}{\text{@ Mid-Depth}} \quad \frac{\text{Gradient}}{\text{Head} \div \text{Distance over which it is Lost}}$$

$$Q = Aki = 14370 \times 0.0040 \times \frac{2.5'}{3"/1."} = 570 \text{ cu.ft. per day}$$

** Seepage through the bottom of west lagoon

$$= Aki = \frac{\text{Area}}{\text{Bottom}} \quad \frac{\text{Permeability}}{\text{Coefficient for sludge blanket}} \quad \frac{\text{Gradient}}{\text{head} \div \text{Distance over which it is Lost}}$$

$$Q = Aki = 74500 \times 0.0012 \times 5'/(5" \div 1")$$

$$" \quad " = 390 \text{ cu.ft. per day}$$

...RA SEWAGE STABILIZATION LAGOON

5	6	7	8	9	10
Seepage (bottom)	Seepage (Lining)	Total Loss	Influent Sta.1	Effluent Sta. 11	Calculated Effluent Sta. 12 8-7
Cu.ft./Day	Cu.ft./Day	Cu. ft./Day	Cu.ft./Day	Cu.ft./Day	Cu.ft./Day
890	570	2890	13860	11540	10970
"	"	2930	15760	13550	12830
"	"	3580	17170	12810	7510
"	"	3150	14640	11850	11490
"	"	4310	13280	12650	8850
"	"	3690	11840	11170	8160
"	"	4210	14620	11310	10410
"	"	3960	14600	12570	12540
"	"	3150	15240	12210	9090
"	"	2910	16780	11540	14170
"	"	3720	14220	11670	10860
				133370	117120

$$\frac{Q_9 - Q_{10}}{Q_9} = \frac{(133370 - 117120)}{133370} \times 100 = 12.2\%$$

Table 3.3

RES ME OF LOSSES FROM EAST LA OON AND A SUMMATION OF THE EAST AND WEST LAGOONS.

Date	1 * Lagoon Evaporation Ft.*	2 Total Evaporation 1 x 79000 Cu.ft./day	3 ** Seepage (Bottom) Cu.ft./day	4 ** Seepage (Dike) Cu.ft./day	5 Total Loss 2+3+4 Cu.ft./day	6 [illegible] Loss Cu.ft./day	7 Total Loss Lagoons 5+6 Cu.ft./day	8 Effluent Std. 12 Gal. per Min.	9 Effluent as Cu.ft./day	10 Calculated Total Effluent 7+9 Cu.ft./day	11 Influent Res ** Cu.Ft./Day
7-20-62	0.0295	1300	2250	300	5550	[illegible]	[illegible]	30	[illegible]	[illegible]	13360
7-21-62	0.0158	1 [illegible]	"	"	[illegible]	2430	7980	40	5760	13740	13760
7-22-62	0.0.56	[illegible]	"	"	[illegible]	3680	4560	28	4040	12600	11170
7-23-62	0.0195	1540	"	"	[illegible]	3130	7940	35	5040	12980	13560
7-24-62	0.0217	1720	"	"	5750	4710	10460	27	3880	14340	11460
7-25-62	[illegible]	2040	"	"	[illegible]	3830	8830	33	4750	13580	11940
7-26-62	0.0317	2503	"	"	5750	3210	[illegible]	31	4460	13710	14720
7-27-62	0.0075	590	"	"	[illegible]	3060	5460	27	3890	11350	14600
7-28-62	0. 195	1540	"	"	4790	3150	7940	31	4460	13360	12260
7-29-62	0.0153	1030	"	"	[illegible]	5610	6 20	28	4030	12250	12792
7-30-62	0.0138	1540	"	"	5150	[illegible]	8550	27	3890	12440	14210
										13[illegible].9	15[illegible]90

$$Q_{ne} = \frac{(A_{e} - A_{w}) \times 100 \times 1.30}{15990}$$

* Values from Column 5 - Summe of Losses from west Raw Sewage Stabilization Lagoon

* Seepage through the side slope of the west lagoon

$$Q = Ak_1 \frac{\text{Area}}{\text{Side Slopes}} \quad \frac{\text{Permeability}}{\text{[illegible]}} \quad \frac{\text{Gradient}}{\text{Head} \div \text{Dike over which it is Lost}}$$

$$Q = Ak_1 = 1100 \text{ [illegible]} \left(\frac{2.}{\text{[illegible]}} = 300 \text{ cu.ft. per day}\right.$$

** Seepage through the bottom of the ea[illegible] lagoon

$$Q = Ak_1 \quad \frac{\text{Area}}{\text{Water}} \quad \frac{\text{Permeability}}{\text{Coefficient for Bluish Blanket}} \quad \frac{\text{Gradient}}{\text{Head over which it is Lost}}$$

$$Q = Ak_1 = 5750 \text{ [illegible]} \times 1^{\prime}/(7 \div 14^{\prime})$$

$$Q = Ak_1 = 1000 \text{ cu.ft. per day}$$

e Total Loss Values from Column 7 - West Lagoon

5e Column 9 = Column 8 x 1440 ÷ 7.5

** Influent Total from Column 8 - West Lagoon

Table 3.

RES ME OF LOSSES FROM EAST LA[illegible]OON AND A SUMMATION OF THE EAST AND

Date	1 * Lagoon Evaporation Feet	2 Total Evaporation 1 x 79000 Cu.ft./Day	3 ** Seepage (Bottom) Cu./Day	4 # Seepage (Side) CF./Day	5 Total Loss 2+3+4 Cu./Day	6 Total Loss Cu.Ft./Day	7 Total Loss Lagoons 5+6 Cu.Ft./Day
7-[illegible]0-62	0.0[illegible]	1300	2350	900	5550	[illegible]	[illegible]
7-31-62	0.0158	1250	"	"	[illegible]	2830	7530
7-[illegible]-62	0.0[illegible]56	2020	"	"	[illegible]	3680	6900
7-[illegible]-62	0.0190	1540	"	"	[illegible]	3150	7940
7-24-62	0.0317	2500	"	"	5750	4210	[illegible]
7-[illegible]-62	0.0256	2020	"	"	[illegible]70	[illegible]	8[illegible]
7-26-62	0.0317	2500	"	"	5750	4210	[illegible]
7-27-62	0.0069	550	"	"	[illegible]	3080	[illegible]
7-28-62	0.[illegible]9[illegible]	1540	"	"	[illegible]	3150	7[illegible]0
7-29-62	0.0133	1050	"	"	[illegible]	[illegible]	6[illegible]0
7-30-62	0.0238	1880	"	"	5130	[illegible]	8[illegible]0

* Values from Column 3 - Summary of Losses from west new sewage stabilization Lagoon

\# Seepage through the side slope of the east lagoon

$$Q = Ak_1 = \frac{\text{Area}}{\text{Side Slopes}} \quad \frac{\text{Permeability}}{\text{[illegible] Coefficient}} \quad \frac{\text{Gradient}}{\text{Head} \div \text{Distance over which it is Lost}}$$

$$Q = Ak_1 = 10800 \text{ [illegible]} \left(\frac{2.}{\text{[illegible]}}\right) = 900 \text{ cu.ft. per day}$$

** Seepage through the bottom of the east lagoon

$$Q = Ak_1 \quad \frac{\text{Area}}{\text{Bottom}} \quad \frac{\text{Permeability}}{\text{Coefficient for Slurry Blanket}} \quad \frac{\text{Gradient}}{\text{Head Distance over which it is Lost}}$$

$$Q = Ak_1 = 67.20 \text{ [illegible]} \text{ A } 5'/(\text{[illegible]} \div 12") \text{ [illegible]}$$

$$Q = Ak_1 = 2350 \text{ cu.ft. per day}$$

AND A SUMMATION OF THE EAST AND WEST LAGOONS.

6 Total Loss	7 Total Loss Lagoons 5+6	8 Effluent Sta. 12	9 Effluent ##	10 Calculated Total Effluent 7+9	11 Influent Sta.1 **
Cu.Ft./Day	Cu.Ft./Day	Gal. Per Min.	Cu.Ft./Day	Cu.Ft./Day	Cu.Ft./Day
9800	9[illegible]	29	5[illegible]7[illegible]	14910	13360
2830	7530	30	57[illegible]0	13[illegible]0	15760
3680	[illegible]920	28	[illegible]380	14[illegible]0	11170
3150	7940	25	1[illegible]0[illegible]	1[illegible]7[illegible]0	14640
4210	[illegible]960	27	[illegible]180	15140	13260
3640	80[illegible]	23	4420	13370	11840
4210	[illegible]0	21	4030	13[illegible]0	14620
3060	5[illegible]	27	[illegible]180	11[illegible]0	14600
3150	7[illegible]0	31	5[illegible]0	13000	12240
3610	6[illegible]0	33	5380	12290	16790
3420	6[illegible]2	27	51[illegible]	13730	14230
				1[illegible]6.0	152990

$$\frac{Q_{in} - Q_{out}}{Q_{in}} = \frac{(1[illegible]0 - 1[illegible]0)}{152990} \times 100 = [illegible]\%$$

* Total Loss Values from Column 7 - West Lagoon

** Column 9 = Column 8 x 1440 ÷ 7.5

** Influent Sta.1 from Column 8 - West Lagoon

Table 3.4

MEASURE OF LOSSES FROM WEST PAM SEWAGE STABILIZATION LAGOON

Date	1 • Pan Evaporation X Inches	2 • Lagoon Evaporation Y Inches	3 Lagoon Evaporation 2 / 12" Feet	4 Total Evaporation 3 x 86700 Cu.Ft./ Day	5 •• Seepage (Bottom) Cf./Day	6 # Seepage (Slope) Cf./Day	7 Total Loss 4+5+6 Cu.Ft./Day	8 Influent Sta.1 Cu.Ft./Day	9 Effluent Sta.11 Cu.Ft./Day	10 Calculated Effluent Sta.12 8-7 Cu.Ft./Day
8-24-62	(0.25)	—	(0.02)	(1730)	890	570	1460	17150	15200	15670
8-25-62	0.437	0.245	0.02	1730	890	570	3190	14000	14430	10810
8-26-62	0.437	0.245	0.02	1730	890	570	3190	12680	12380	9490
8-27-62	0.562	0.268	0.22	1910	890	570	3370	14390	12430	11020
8-28-62	0.500	0.239	0.02	1730	890	570	3190	11400	11830	8210
									65270	55200

• Evaporation on Lagoon: Y = 0.477X + 0.006

•• Value from Column 5, Table 3.3

Value from Column 6, Table 3.3

$$\frac{Q - Q_1}{Q_1} = \frac{(65270 - 55200)}{65270} \times 100 = 10.83\%$$

MEASURE OF LOSSES FROM EAST LAGOON AND A SUMMATION OF THE EAST AND WEST LAGOONS

Date	1 ∮ Lagoon Evaporation Feet	2 Total Evaporation 1 x 79000 Cu.Ft./Day	3 •••• Seepage (Bottom) Cf./Day	4 ••• Seepage (Slope) Cf./Day	5 Total Loss 2+3+4 Cf./Day	6 Total Loss ∮ Cu.Ft./Day	7 Total Loss Lagoons 5+6 Cu.Ft./Day	8 Effluent Sta.12 Gal. Per Min.	9 Effluent ∮∮ Cf./Day	10 Calculated Total Effluent 7 + Cu.Ft./Day	11 Influent Sta ∮∮∮ Cu.Ft./Day
8-24-62	(0.02)	(1580)	2350	900	3250	1460	3710	34.0	6720	10430	17130
8-25-62	0.02	1580	2350	900	4830	3190	8020	29.3	5820	13840	14000
8-26-62	0.02	1580	2350	900	4830	3190	8020	26.6	5110	13130	12680
8-27-62	0.22	1740	2350	900	4990	3370	8360	26.6	5110	13470	14390
8-28-62	0.02	1580	2350	900	4830	3190	8020	24.5	4700	12720	11400
										65390	79120

•••• Value From Column 3, Table 3.4

••• Value From Column 4, Table 3.4

∮ From Column 3 Above

$(Q_2 - Q_1)/Q_1 = (65390 - 55200)/65270 = 0.1092$ or 10.92%

Total Loss Values from Column 7 - West Lagoon

Column = Column 8 x 1440 ÷ 7.5

Influent Sta.1 from Column 8 - West Lagoon

Table 3.5

95% compaction. This value was found to be 0.085 feet per day. Two other tests were performed on the 95% compacted soil using an additive of 1/2 of 1% by dry weight of bentonite in one, and 1/2 of 1% of dry weight of Portland cement in the other. The resulting coefficients of permeability for the modified soil were identical, 0.019 feet per day. Detailed information related to the tests is provided in Tables 3.6, 3.7, and 3.8. When the lagoons were constructed, the west lagoon received no stabilization treatment; however, the east lagoon received 500 bags of Portland cement distributed over its designed wetted area.

In order to determine the self-sealing potential of the lagoons, it was necessary to extract samples from both within and without the wetted area. All sampling locations are identified in Figure 1.2. Soil samples were removed from within the wetted area by means of sampling equipment composed of driving and lifting apparatus as illustrated in Figures 3.7 and 3.8. The apparatus was placed, operated, and transported by boat.

Soil samples outside the wetted area were extracted with a standard 3.5 inch post hole auger assembly shown in Figure 3.9. The driving and lifting apparatus previously described was modified for use in this area.

Vertical sampling intervals were determined by the changing soil horizons, but in no case were samples removed at greater than one foot intervals. Undisturbed samples were extracted by means of the Shelby tubing assembly illustrated in Figures 3.10 and 3.11. Each 24-inch tube with the soil sample in place was sawed into 5-inch increments beginning at the cutting edge. Each increment was identified

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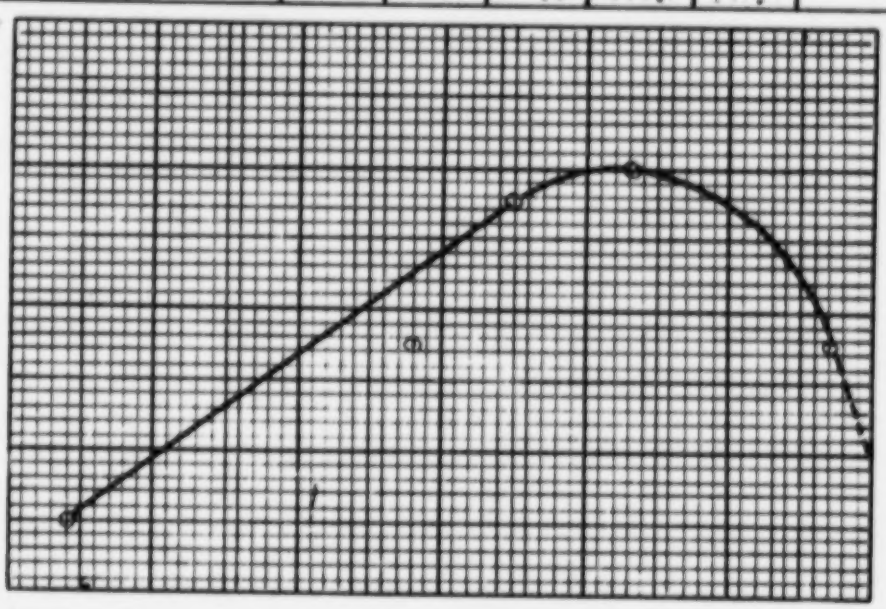
UNIVERSITY OF ARIZONA
SOIL MECHANICS LABORATORY
COMPACTION CHARACTERISTICS

Sample No. A Name [illegible] Date [illegible]

Source of Sample **Stabilisation Pond Site**

Method of Test: ☐ Std AASHO. ☐ Mod AASHO ☐ Other (describe) _____

Trial	1	2	3	4	5	6	7
Wt of Mold + Wet Soil, gm							
Wt of Mold, gm							
Wt of Wet Soil, gm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Wet Density, lbs/cu.ft	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Plasticity Needle No.							
Footing Area, sq in							
Penetration, Reading, lbs.							
Penetration Resistance, lbs/sq in.							
Moisture Can No.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Wt of Can + Wet Soil, gm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Wt of Can + Dry Soil, gm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Wt of Moisture, gm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Wt of Can + Dry Soil, gm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Wt of Can, gm Wt of Dry Soil, gm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
MOISTURE CONTENT, %	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
DRY DENSITY lbs/cu ft	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		



DENSITY in lbs/cu ft

PENETRATION RESISTANCE in lbs/sq in.

MOISTURE CONTENT in %

Max Dry Density [illegible] lbs/cu.ft. Optimum Moisture Content 16.3 % Penetration Val. ___ psi

Table 3.6

UNIVERSITY OF ARIZONA

SOIL MECHANICS LABORATORY

Permeability Tests

Sample No. A Boring No. ____ Depth 4' Name Haynie, R. M. Date 12/12/59

Source of Sample Stabilization Pond Site - Sanitary District

State of Sample ☐ Undisturbed, ☒ Remolded, Visual Textural Classification (fine) sandy silt

Remarks Remold to 95% of max. dry density

FALLING HEAD TEST

Cross-sectional Area of Standpipe, (a)	.074 sq. in.	0.479 sq. cm.
Cross-sectional Area of Sample (A)	1.32 sq. in.	8.52 sq. cm.
Length of Sample, (L)	2.80 in.	7.10 cm.
Initial Level of Water in Standpipe, (h_1)	14.3 in.	36.32 cm.
Final Level of Water in Standpipe, (h_2)	13.3 in.	33.78 cm.

Trial	1	2	3
Time, (+)	86,400 Sec.	____ Sec.	____ Sec.
Water Temperature	24 ° C.	____ ° C.	____ ° C.
Permeameter Constant, (C) = $\frac{2835 \cdot 2.3\ a \cdot L}{A} \times \log_{10}\left(\frac{h_1}{h_2}\right)$			806
Coefficient of Permeability, (k) (uncorrected)	0.093 ft/day	____ ft/day	____ ft/day

Average Coefficient of Permeability (k) (uncorrected for temperature) 0.093 ft/day

Temperature Correction Factor = $\frac{\text{(Coeff. of viscosity at av. test temp.)}}{\text{(Coeff. of viscosity at } 20^\circ \text{ C)}}$ 0.91

Corrected Average Coefficient of Permeability, (k) 0.085 ft/day

Table 3.7

UNIVERSITY OF ARIZONA

SOIL MECHANICS LABORATORY

Permeability Tests

Sample No. 2 Boring No. ____ Depth 4' Name R. L. Sloane Date 2/18/60

Source of Sample Stabilization Pond Site - Sanitary District

State of Sample ☐ Undisturbed, ☒ Remolded, Visual Textural Classification Fine Silty Sand

Remarks Sample number corresponds to field number

Note: 1/2% by dry wt. bentonite added to soil. Same results with 1/2% Portland cement.

FALLING HEAD TEST

Cross-sectional Area of Standpipe, (a)	0.0767 sq. in.	0.502 sq. cm.	
Cross-sectional Area of Sample, (A)	1.354 sq. in.	8.73 sq. cm.	
Length of Sample, (L)	2.813 in.	7.14 cm.	
Initial Level of Water in Standpipe, (h_1)	____ in.	36.2 cm.	
Final Level of Water in Standpipe, (h_2)	____ in.	15.4 cm.	
Trial	1	2	3
Time, (+)	48,000 Sec.	____ Sec.	____ Sec.
Water Temperature	24 ° C.	____ ° C.	____ ° C.
Permeameter Constant, (C) = $\frac{2835 \cdot 2.3\ a \cdot L}{A} \times \log_{10} \frac{h_1}{h_2}$			992.0
Coefficient of Permeability, (k) (uncorrected)	0.021 ft/day	____ ft/day	____ ft/day

Average Coefficient of Permeability (k) (uncorrected for temperature) 0.021 ft/day

Temperature Correction Factor = $\frac{\text{(Coeff. of viscosity at av. test temp.)}}{\text{(Coeff. of viscosity at 20° C)}}$ 0.93

Corrected Average Coefficient of Permeability, (k) 0.0195 ft/day

Table 3.8

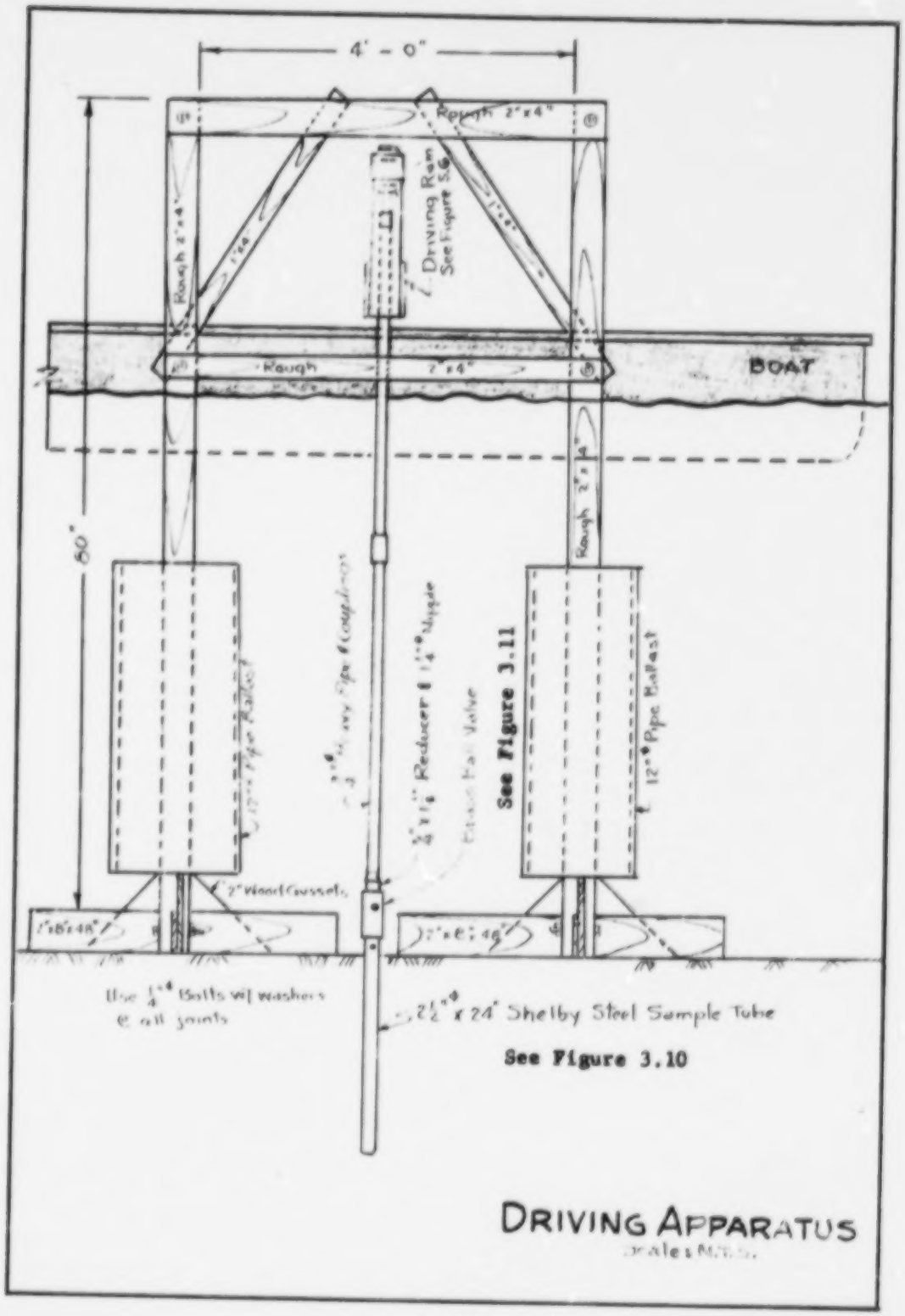

4' - 0"
Rough 2"x4"
Driving Ram
See Figure 3.6
Rough 2"x4"
Rough 2"x4"
BOAT
Rough 2"x4"
80"
See Figure 3.11
12"ϕ Pipe Ballast
2" Wood Gussets
Use 1/4" ϕ Bolts w/ washers
@ all joints
2 1/2" ϕ x 24" Shelby Steel Sample Tube
See Figure 3.10
DRIVING APPARATUS

Figure 3.7

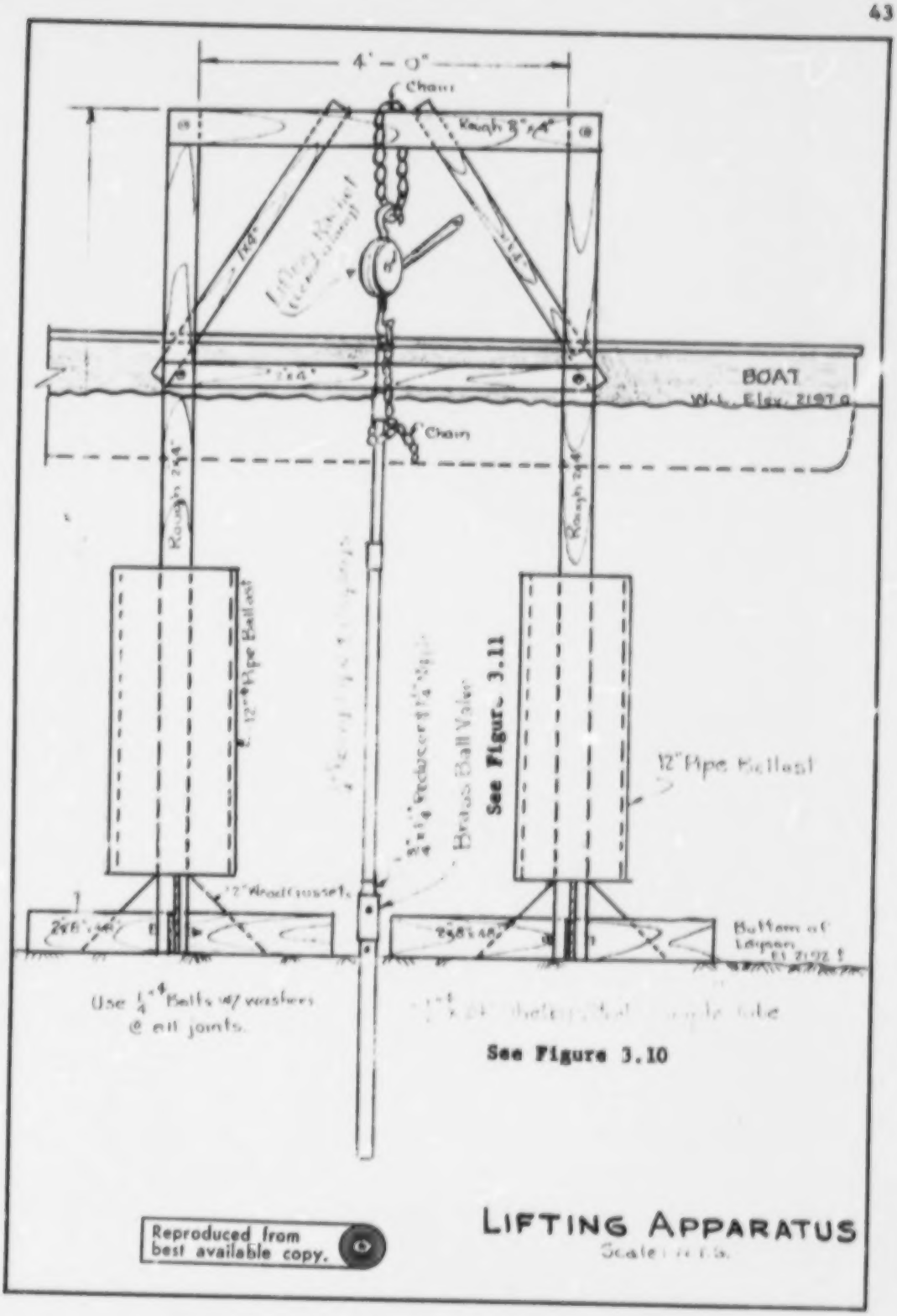


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Figure 3.8

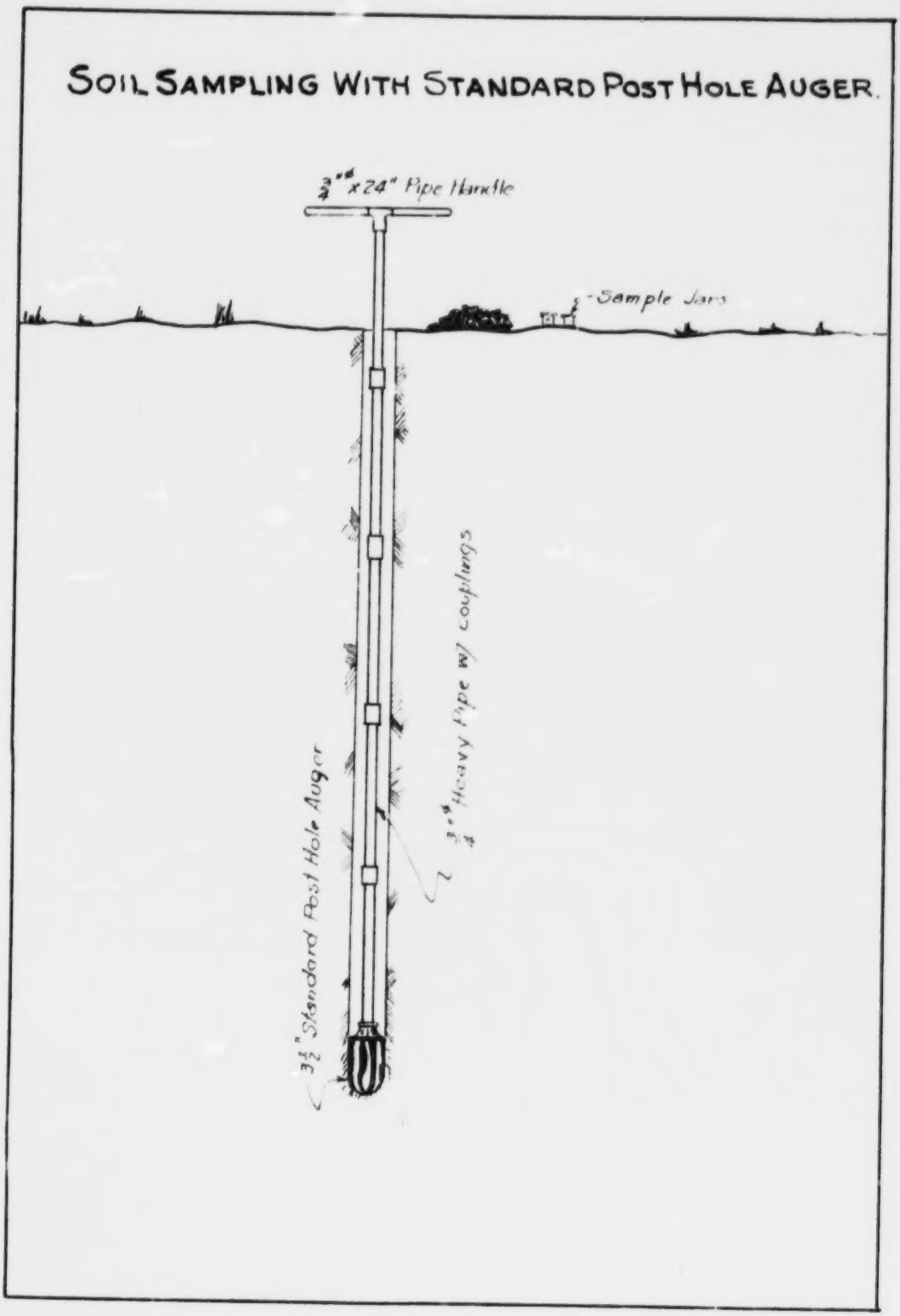

SOIL SAMPLING WITH STANDARD POST HOLE AUGER.
¾" x 24" Pipe Handle
Sample Jars
1" Heavy Pipe w/ couplings
3½" Standard Post Hole Auger

Figure 3.9

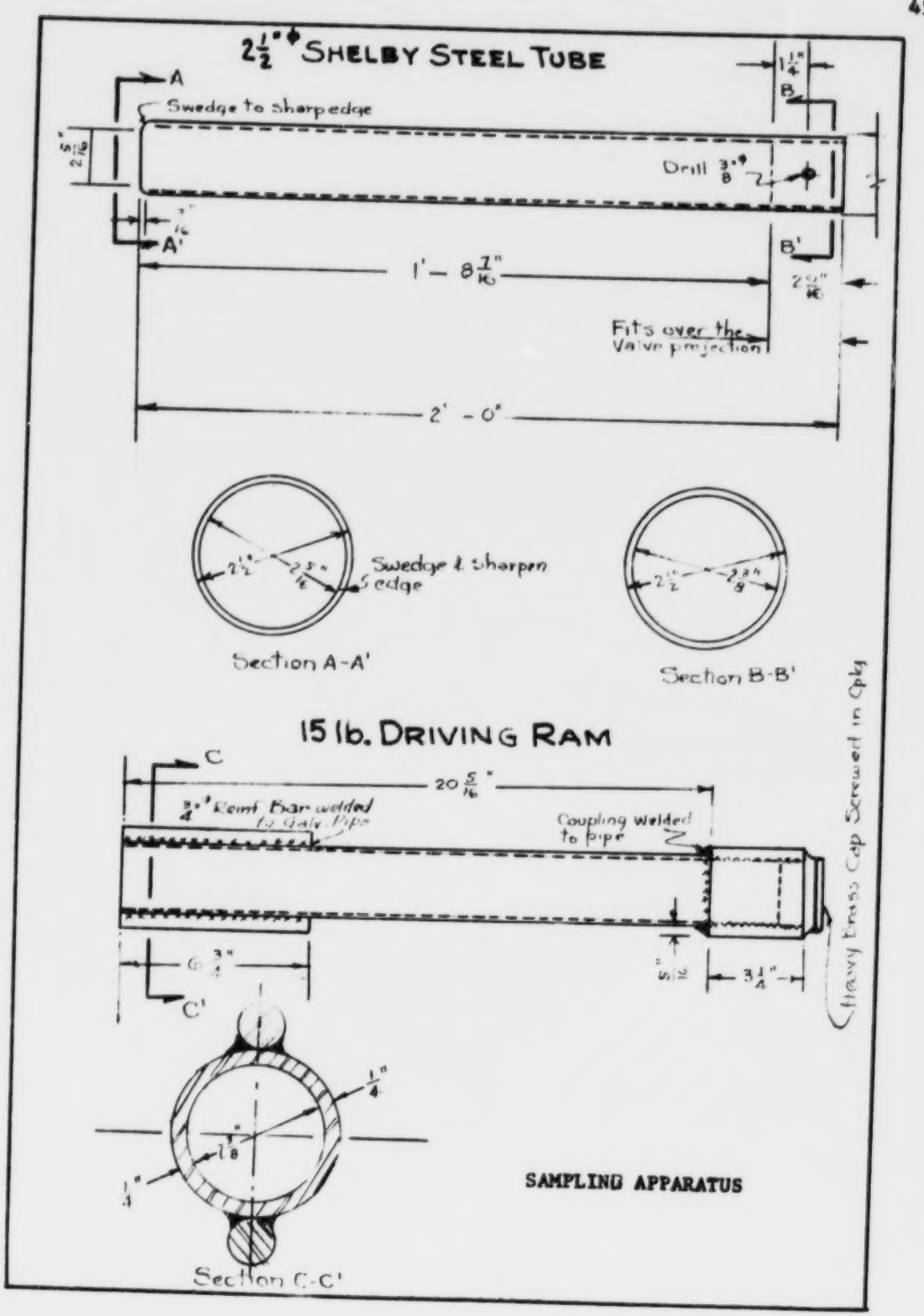

2½" ϕ SHELBY STEEL TUBE
A
Swedge to sharpedge
Drill 3/8" ϕ
A'
B
B'
1'– 8 7/16"
Fits over the Valve projection
2' - 0"
Swedge & Sharpen edge
Section A-A'
Section B-B'
15 lb. DRIVING RAM
C
20 5/16"
3/4" Reinf. Bar welded to Galv. Pipe
Coupling welded to pipe
C'
Heavy brass Cap Screwed in Opg
1/4"
1/8"
Section C-C'
SAMPLING APPARATUS

Figure 3.10

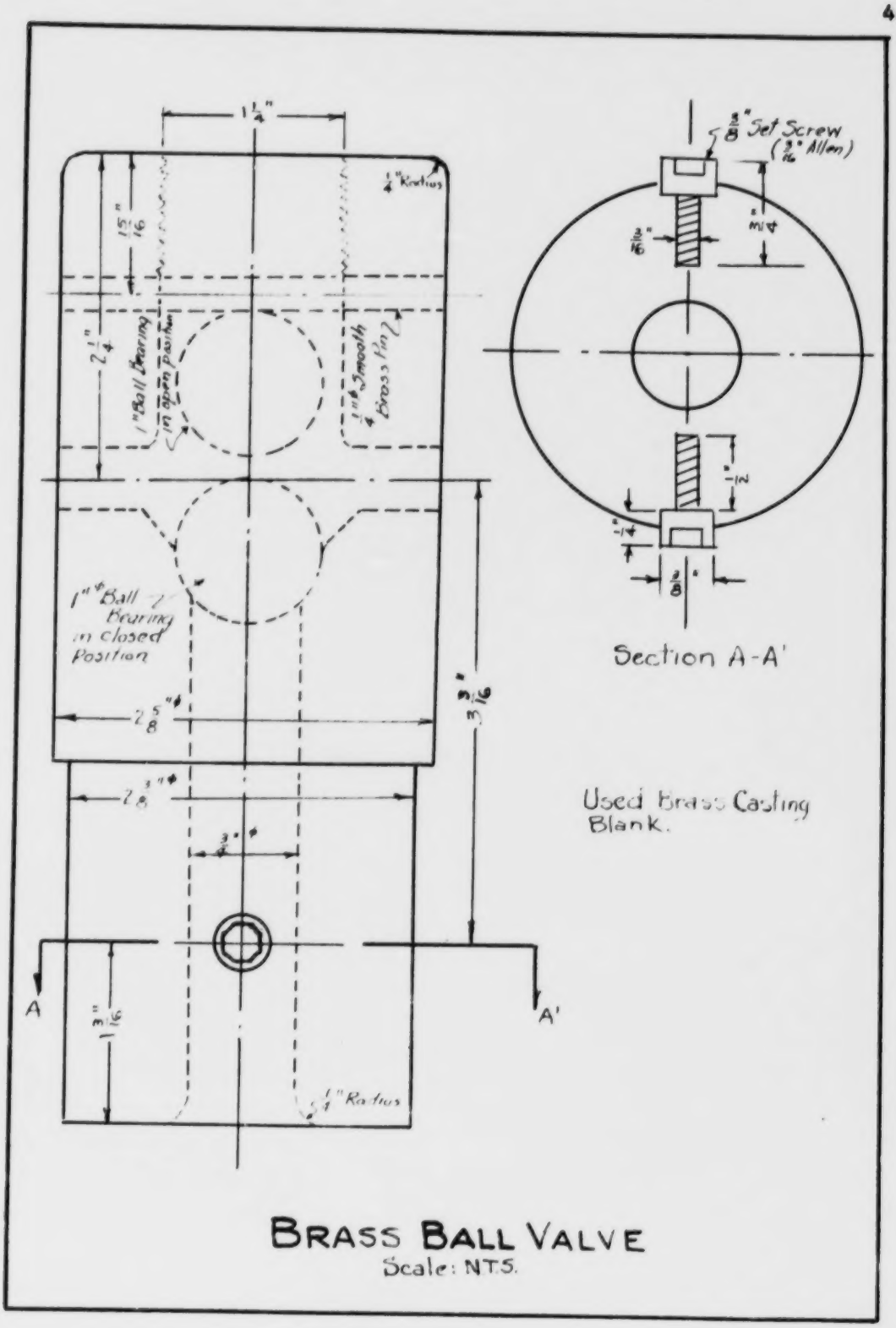

1 1/4"
1/4" Radius
15/16"
2 1/4"
1" Ball Bearing in open position
1" Smooth Brass Pin
1" Ball Bearing in closed Position
2 5/8" ϕ
2 3/8" ϕ
3/4" ϕ
3 3/16"
3 1/16"
1" Radius
A
A'
3/8" Set Screw (3/16" Allen)
Section A-A'
Used Brass Casting Blank.
BRASS BALL VALVE
Scale: N.T.S.

Figure 3.11

and marked as to the direction the sample entered the tube. Cores from each increment were prepared for standard permeability apparatus. This procedure is illustrated in Figure 3.12. The coefficient of permeability (k) was determined by the Standard Method of Variable Head Permeability Test[22]. Excess soil was analyzed for moisture content by the standard method.

As a result of difficulties encountered in securing an undisturbed benthal deposit sample, especially from the east lagoon, it was found necessary to develop a modified procedure for determining the coefficient of permeability "k" value for the benthal blanket. For purposes of discussion, this procedure has been designated as "Method X". The procedure involved long-term permeability observations using the entire undisturbed sample contained in the 24-inch Shelby sampling tube. Details of this procedure are presented in Figure 3.13.

The soils from the various horizons were classified in accordance with standard soil classification practices[22,24,25]. Field capacity determinations were made in accordance with the procedure outlined in Figure 3.14.

Mathematical procedures used in determining the coefficient of permeability as well as the values resulting from the determination are presented in Figures 3.15 to 3.17 inclusive. Similar information related to seepage computations, soil classification, soil borings, volatile matter, moisture content, and field capacity are presented in Figures 3.18 to 3.26 inclusive.

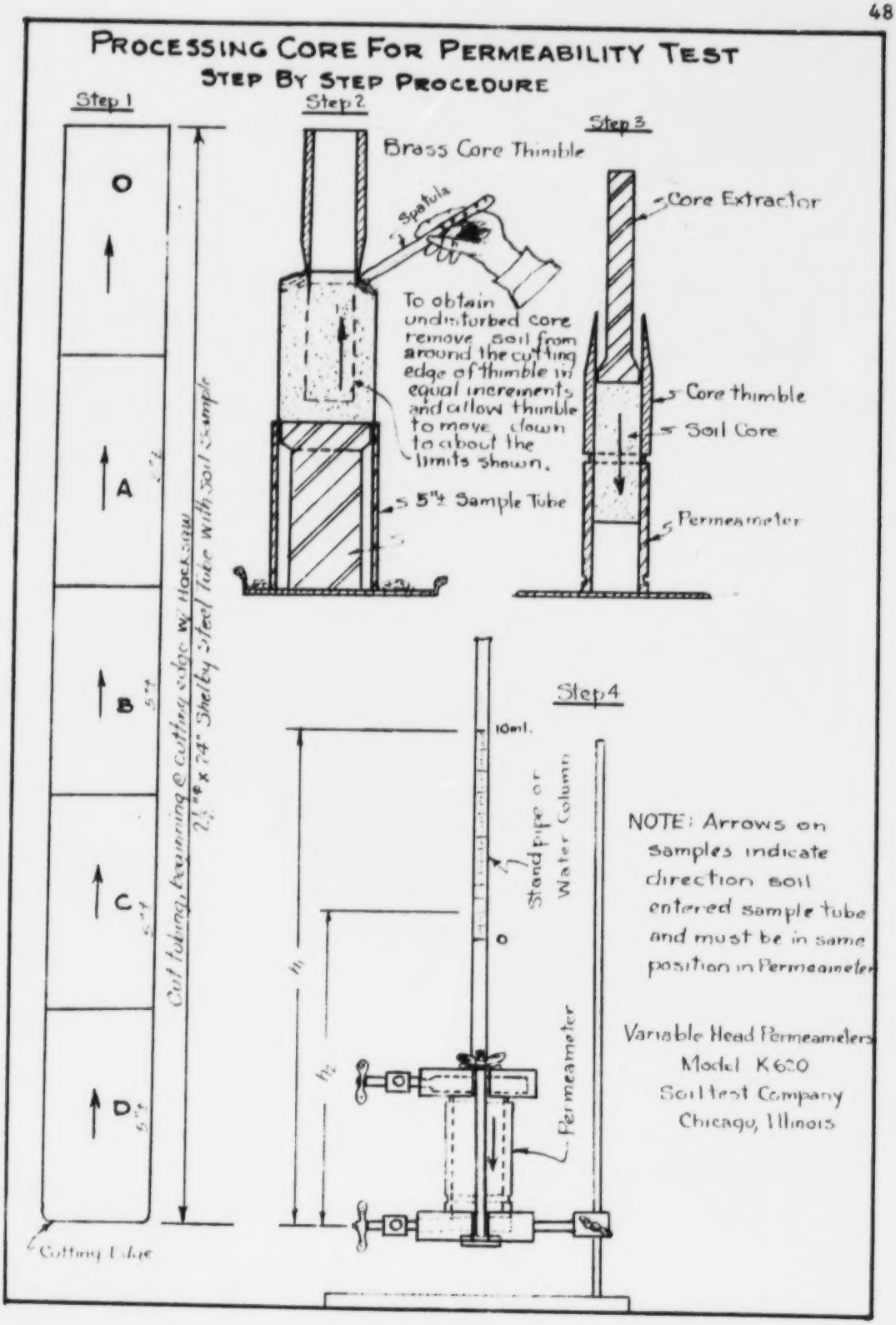

PROCESSING CORE FOR PERMEABILITY TEST
STEP BY STEP PROCEDURE
Step 1
Step 2
Step 3
Step 4
Brass Core Thimble
Spatula
To obtain undisturbed core remove soil from around the cutting edge of thimble in equal increements and allow thimble to move down to about the limits shown.
5" Sample Tube
Core Extractor
Core thimble
Soil Core
Permeameter
Cut tubing, beginning @ cutting edge w/ hacksaw
2.5" x 24" Shelby Steel Tube with Soil Sample
O
A
B
C
D
Cutting Edge
10ml.
Stand pipe or Water Column
Permeameter
NOTE: Arrows on samples indicate direction soil entered sample tube and must be in same position in Permeameter
Variable Head Permeameters
Model K620
Soil Test Company
Chicago, Illinois

Figure 3.12

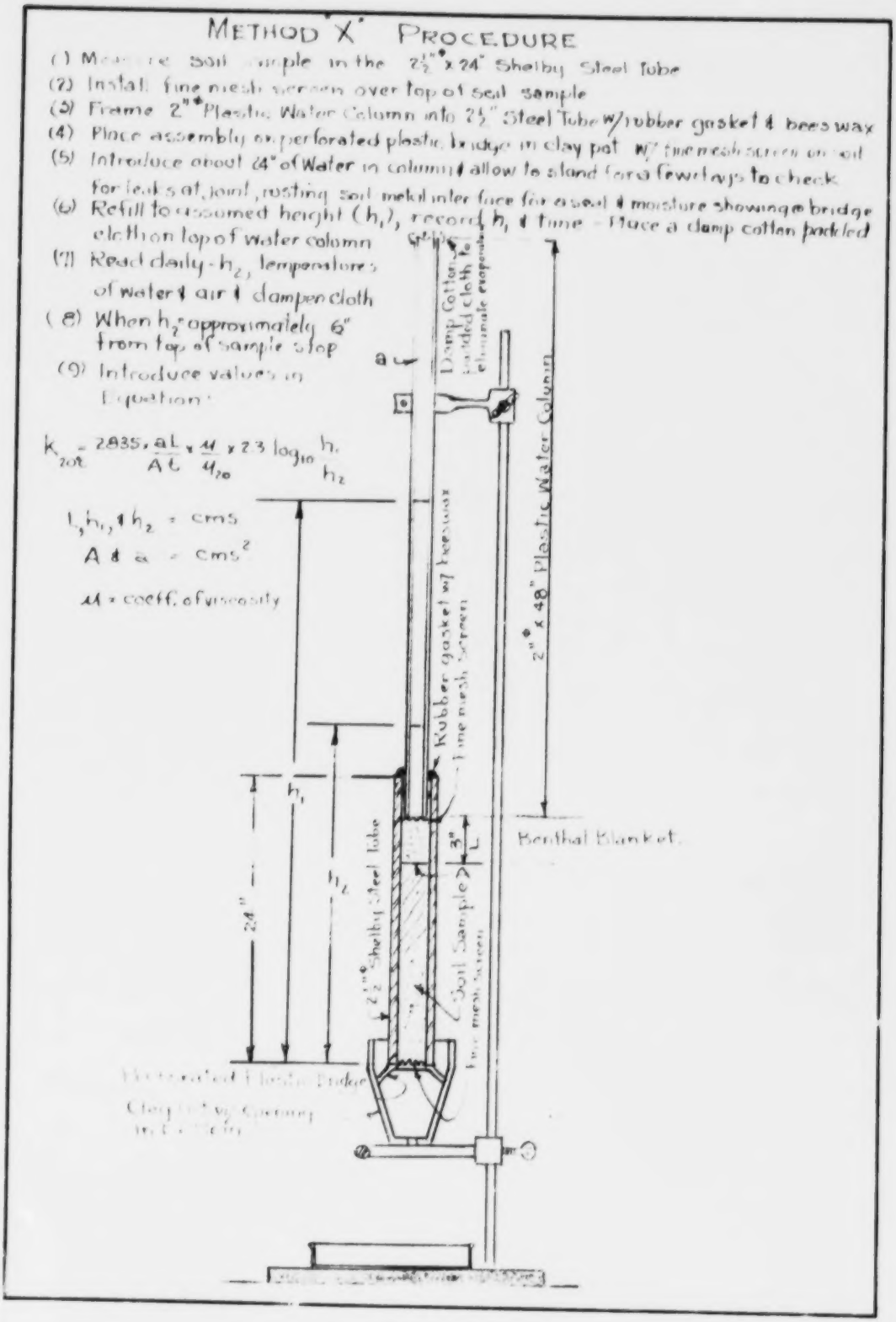
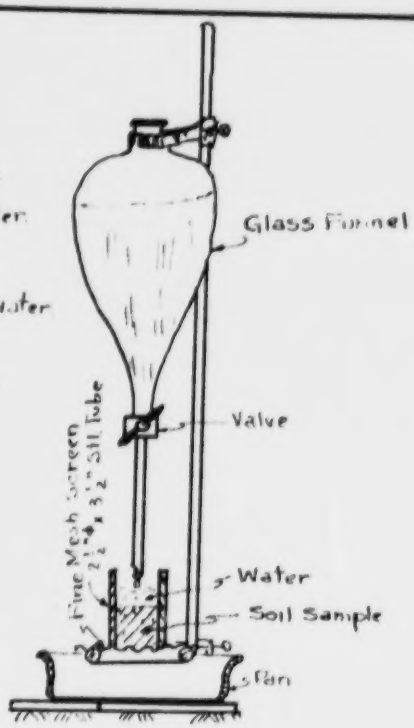

METHOD "X" PROCEDURE
(1) Measure soil sample in the 2½" x 24" Shelby Steel Tube
(2) Install fine mesh screen over top of soil sample
(3) Frame 2" Plastic Water Column into 2½" Steel Tube w/rubber gasket & bees wax
(4) Place assembly on perforated plastic bridge in clay pot w/ fine mesh screen on soil
(5) Introduce about 24" of Water in column & allow to stand for a few days to check for leaks at joint, resting soil mold interface for a seal & moisture showing@ bridge
(6) Refill to assumed height (h_1), record h_1 & time - Place a damp cotton packed cloth on top of water column
(7) Read daily - h_2, temperature of water & air & dampen cloth
(8) When h_2 approximately 6" from top of sample stop
(9) Introduce values in Equation:
$K_{20} = 2.835 \frac{aL}{At} \times \frac{\mu}{\mu_{20}} \times 2.3 \log_{10} \frac{h_1}{h_2}$
L, h_1, & h_2 = cms
A & a = cms^2
μ = coeff. of viscosity
Damp Cotton packed cloth to eliminate evaporation
a
2" x 48" Plastic Water Column
Rubber gasket w/ beeswax
fine mesh screen
Benthal Blanket
3"
L
h_1
h_2
24"
2½" Shelby Steel Tube
Soil Sample
fine mesh screen
Perforated Plastic Bridge
Clay Pot w/ Coating of Bees Wax

Figure 3.13

PROCEDURE

(1) Extract 2½"Ø x 4" Sample from lagoon
(2) Seal with saran & foil
(3) Transport to laboratory
(4) Setup apparatus as shown
(5) Fill glass funnel w/ water and adjust valve until soil sample covered w/ water
(6) Water drips into pan from sample; saturation attained
(7) Allow sample to drain free of gravity water
(8) Take soil samples, weigh (W_w) & dry in oven as per Standard Method
(9) From oven to desiccator
(10) Weighed (dry) W_D
(11) Field Capacity(%) $\frac{W_w - W_D}{W_D} \times 100$



FIELD CAPACITY			
PB-7		PB-8	
ELEV.	%	ELEV	%
2192	25.45	2191	27.4
2191	38.88	2189	25.7
2187	34.58	2186	23.6
2184.3	26.20		

FIELD CAPACITY ANALYSIS

Figure 3.14

DETERMINATION OF COEFFICIENT OF PERMEABILITY

$k = aL/At \times u/u_{20^oC} \times \log h_1/h_2$

See Figures 3.12 and 3.13 showing the Standard Variable Head Permeameter and Method "X".

k = centimeters per second

a = area of stand pipe, in square centimeters

A = area of soil sample, in square centimeters

L = length of soil sample, in centimeters

t = time, in seconds

u = coefficient of viscosity at average test temperature

u_{20^oC} = coefficient of viscosity at 20° Centigrade

h_1 = initial level of water in stand pipe, in centimeters

h_2 = final level of water in stand pipe, in centimeters

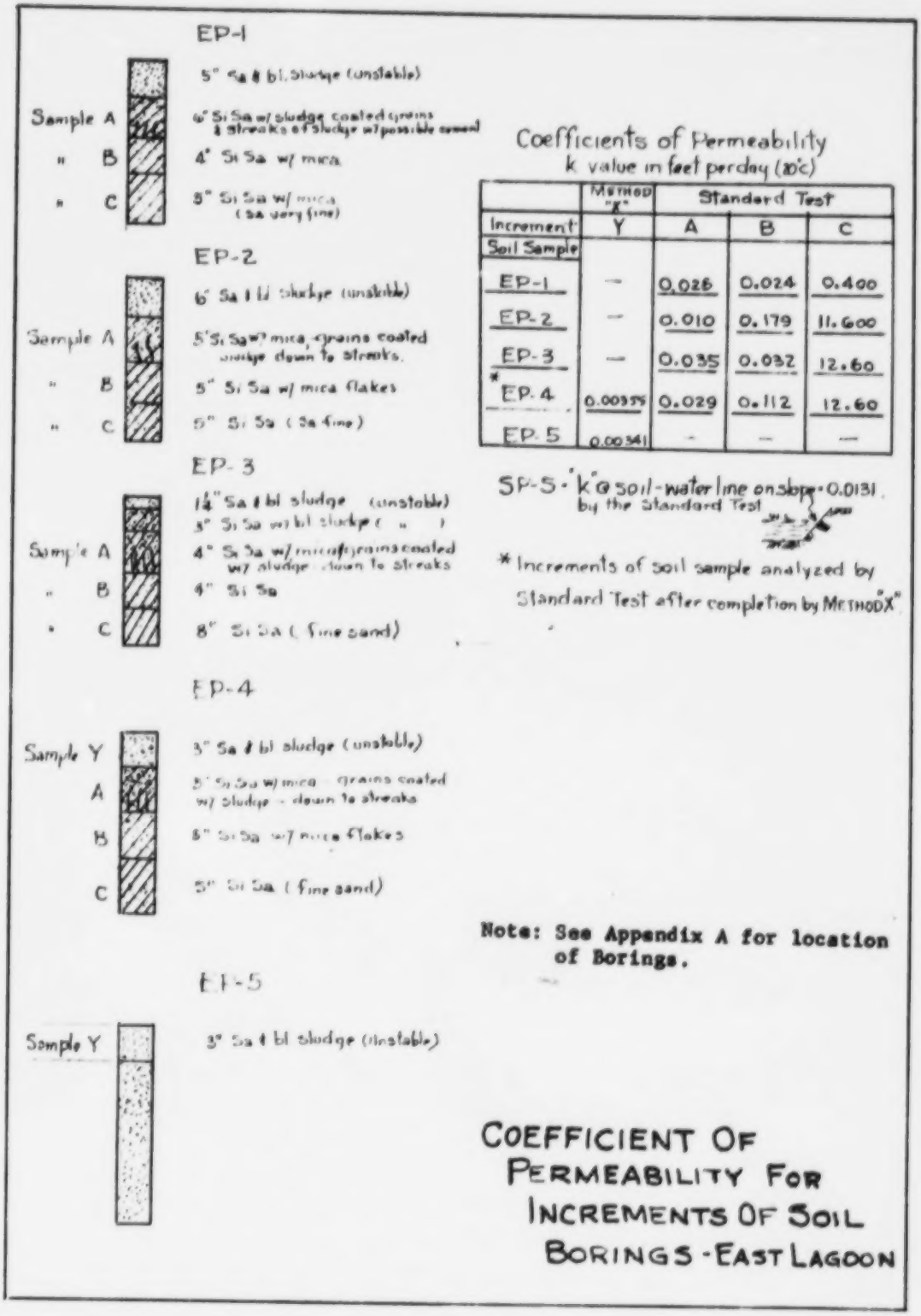
CONVERSION OF COEFFICIENT OF PERMEABILITY IN TERMS OF FEET PER DAY

$$k_{20^oC} = \frac{0.3937 \times 86400}{12} \times 2.3 \times \frac{aL}{At} \times \log \frac{h_1}{h_2} \times \frac{u}{u_{20^oC}}$$

or

$$k_{20^oC} = 2835 \times 2.3 \times \frac{aL}{At} \times \log \frac{h_1}{h_2} \times \frac{u}{u_{20^oC}} = \text{feet per day}$$

Figure 3.15


EP-1
5" Sa & bl. Sludge (unstable)
Sample A
6" Si Sa w/ sludge coated grains & streaks of sludge w/ possible seam
B
4" Si Sa w/ mica
C
5" Si Sa w/ mica (Sa very fine)
EP-2
6" Sa & bl sludge (unstable)
Sample A
5" Si Sa w/ mica, grains coated sludge down to streaks.
B
5" Si Sa w/ mica flakes
C
5" Si Sa (Sa fine)
EP-3
1¼" Sa & bl sludge (unstable)
3" Si Sa w/ bl sludge (")
Sample A
4" Si Sa w/ mica grains coated w/ sludge - down to streaks
B
4" Si Sa
C
8" Si Sa (fine sand)
EP-4
Sample Y
3" Sa & bl sludge (unstable)
A
5" Si Sa w/ mica - grains coated w/ sludge - down to streaks
B
5" Si Sa w/ mica flakes
C
5" Si Sa (fine sand)
EP-5
Sample Y
3" Sa & bl sludge (unstable)

Coefficients of Permeability
k value in feet per day (20°c)

	Method "X"	Standard Test		
Increment*	Y	A	B	C
Soil Sample				
EP-1	—	0.026	0.024	0.400
EP-2	—	0.010	0.179	11.600
EP-3	—	0.035	0.032	12.60
EP-4	0.00355	0.029	0.112	12.60
EP-5	0.00341	—	—	—

SP-S - k @ soil-water line on slope = 0.0131 by the Standard Test

* Increments of soil sample analyzed by Standard Test after completion by METHOD "X"

Note: See Appendix A for location of Borings.

COEFFICIENT OF PERMEABILITY FOR INCREMENTS OF SOIL BORINGS - EAST LAGOON

Figure 3.16

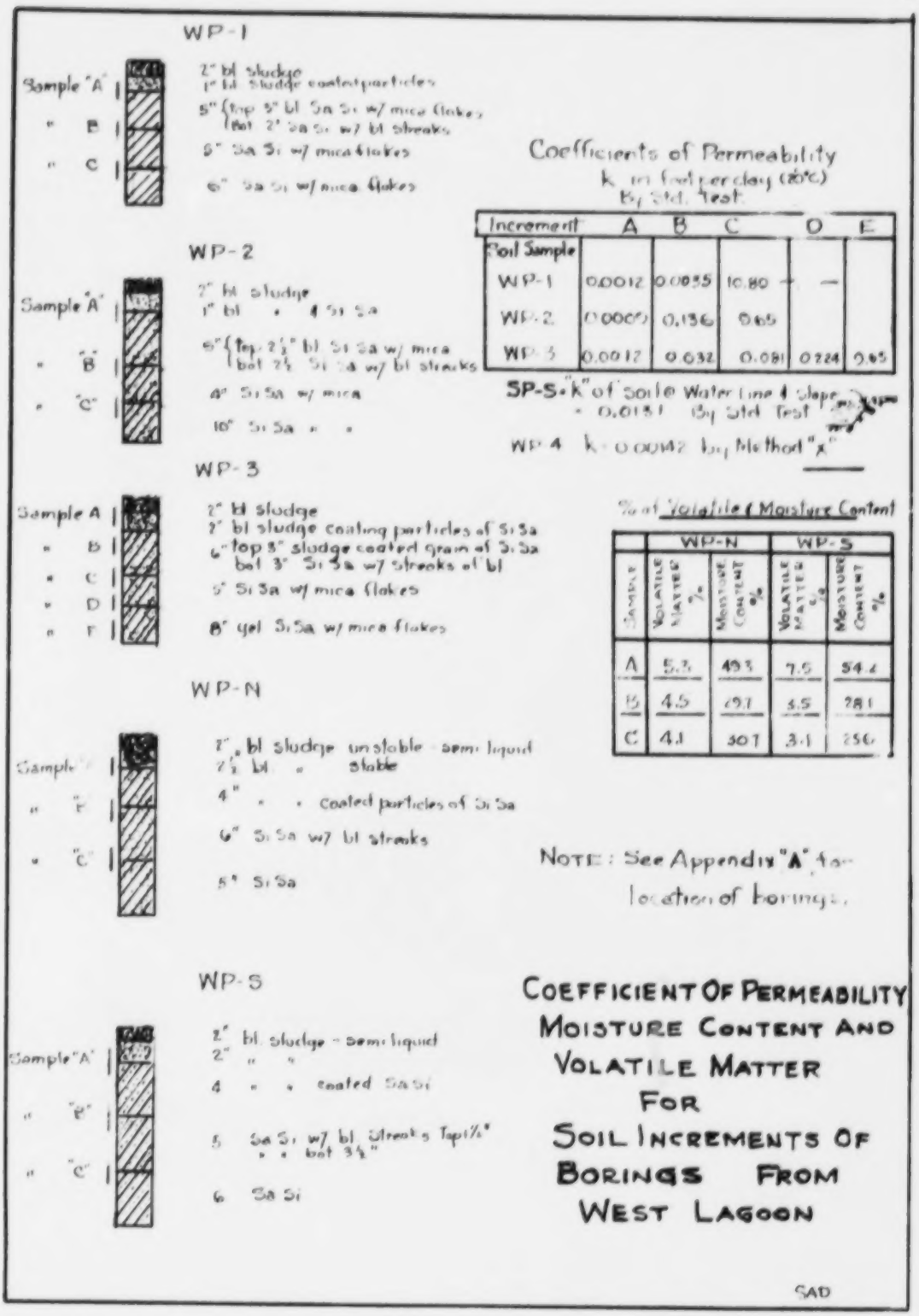

WP-1
Sample "A"
" B
" C
2" bl sludge
1" bl sludge coated particles
5" (top 3" bl Sa Si w/ mica flakes
bot 2" Sa Si w/ bl streaks
5" Sa Si w/ mica flakes
6" Sa Si w/ mica flakes
WP-2
Sample "A"
" "B"
" "C"
2" bl sludge
1" bl " & Si Sa
5" (top 2½" bl Si Sa w/ mica
bot 2½ Si Sa w/ bl streaks
4" Si Sa w/ mica
10" Si Sa " "
WP-3
Sample A
" B
" C
" D
" E
2" bl sludge
2" bl sludge coating particles of Si Sa
6" top 3" sludge coated grain of Si Sa
bot 3" Si Sa w/ streaks of bl
5" Si Sa w/ mica flakes
8" yel Si Sa w/ mica flakes
WP-N
Sample "A"
" "B"
" "C"
1" bl sludge unstable - semi liquid
2½ bl " stable
4" " " coated particles of Si Sa
6" Si Sa w/ bl streaks
5" Si Sa
WP-S
Sample "A"
" "B"
" "C"
2" bl sludge - semi liquid
2" " "
4 " " coated Sa Si
5 Sa Si w/ bl streaks top 1½"
" " bot 3½"
6 Sa Si
Coefficients of Permeability
k in feet per day (20°C)
By Std. Test
Increment | A | B | C | D | E
Soil Sample
WP-1 | 0.0012 | 0.0035 | 10.80 | — | —
WP-2 | 0.0005 | 0.136 | 0.65 | | —
WP-3 | 0.0012 | 0.032 | 0.081 | 0.224 | 0.65
SP-S "k" of Soil @ Water Line & Slope = 0.0131 By Std Test
WP-4 k = 0.0042 by Method "X"
% of Volatile & Moisture Content
WP-N | WP-S
Sample | Volatile Matter % | Moisture Content % | Volatile Matter % | Moisture Content %
A | 5.3 | 49.3 | 7.5 | 54.2
B | 4.5 | 29.1 | 5.5 | 28.1
C | 4.1 | 30.7 | 3.1 | 25.6
NOTE: See Appendix "A" for location of borings.
COEFFICIENT OF PERMEABILITY MOISTURE CONTENT AND VOLATILE MATTER FOR SOIL INCREMENTS OF BORINGS FROM WEST LAGOON
SAD

Figure 3.17

COMPUTATION OF SEEPAGE THROUGH THE SUBMERGED AREA OF LAGOONS

Darcy's law presented in 1856, states the velocity of flow of water through a column of soil is directly proportional to the difference in pressure head and inversely proportional to the length of the column.

$v = k\ h/l$

$Av = A\ k\ h/l$

$Q = A\ k\ i$

Q = rate of flow, cubic centimeters per second

v = velocity, in centimeters per second

l = length of column, in centimeters

i = gradient, h/l

h = difference in pressure head, in centimeters

k = coefficient of permeability at 20 degrees Centigrade

Seepage through the bottom and the side slopes of the submerged area was computed as follows:

$$Q_{Bottom} = \frac{\text{Area of Bottom}}{\text{Square Feet}} \times \frac{\text{Permeability "k" of Sludge Blanket in Feet/Day}}{} \times \frac{\text{Gradient h/l}}{\text{Foot/Foot}}$$

$$Q_{Slope} = \frac{\text{Area of Bottom}}{\text{Square Feet}} \times \frac{\text{Permeability at Mid-Slope Feet/Day}}{} \times \frac{\text{Gradient h/l}}{\text{Foot/Foot}}$$

Q = rate of flow, in cubic feet per day

Figure 3.18

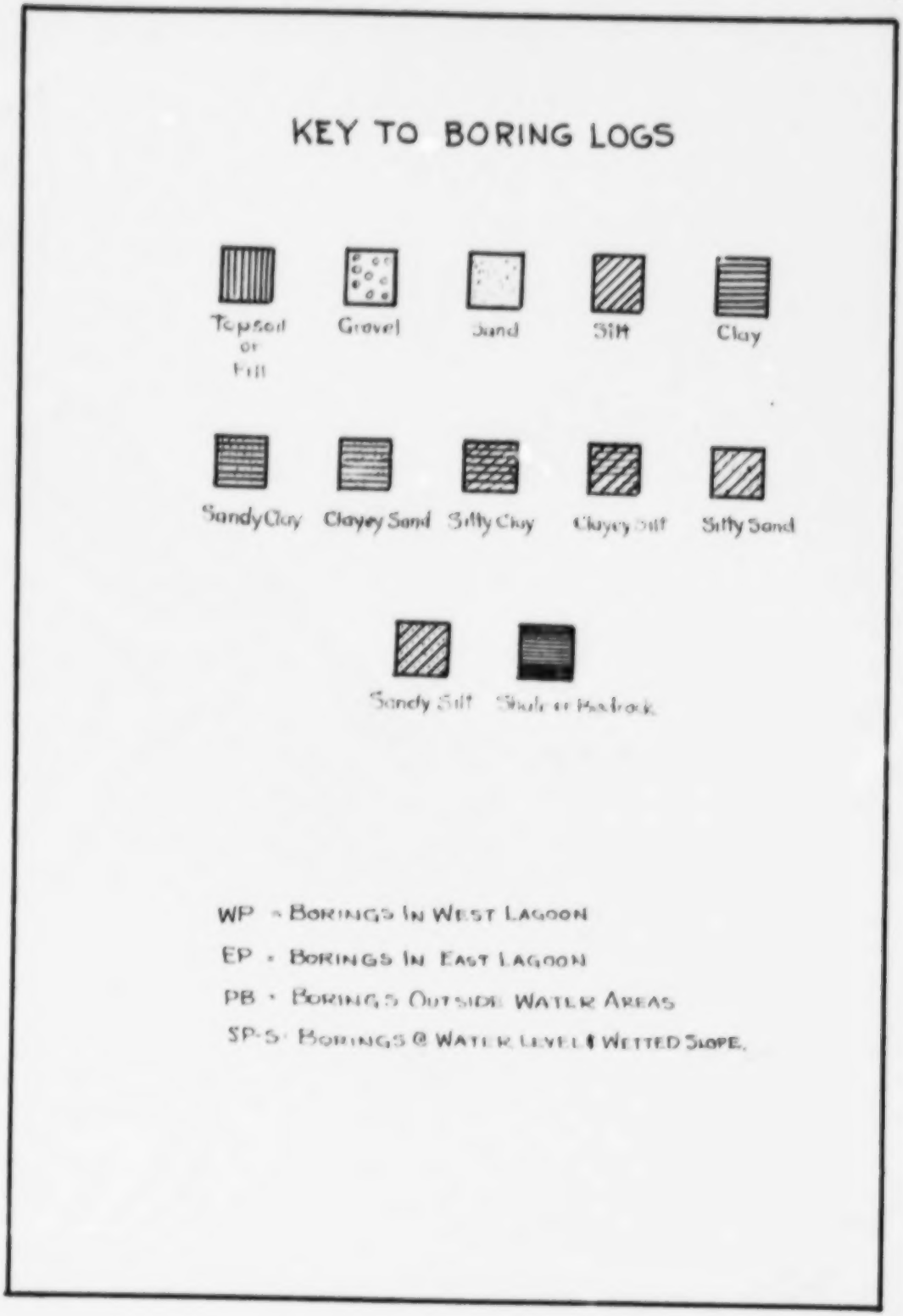

KEY TO BORING LOGS
Topsoil or Fill
Gravel
Sand
Silt
Clay
Sandy Clay
Clayey Sand
Silty Clay
Clayey Silt
Silty Sand
Sandy Silt
Shale or Bedrock
WP - Borings In West Lagoon
EP - Borings In East Lagoon
PB - Borings Outside Water Areas
SP-S - Borings @ Water Level & Wetted Slope.

Figure 3.19

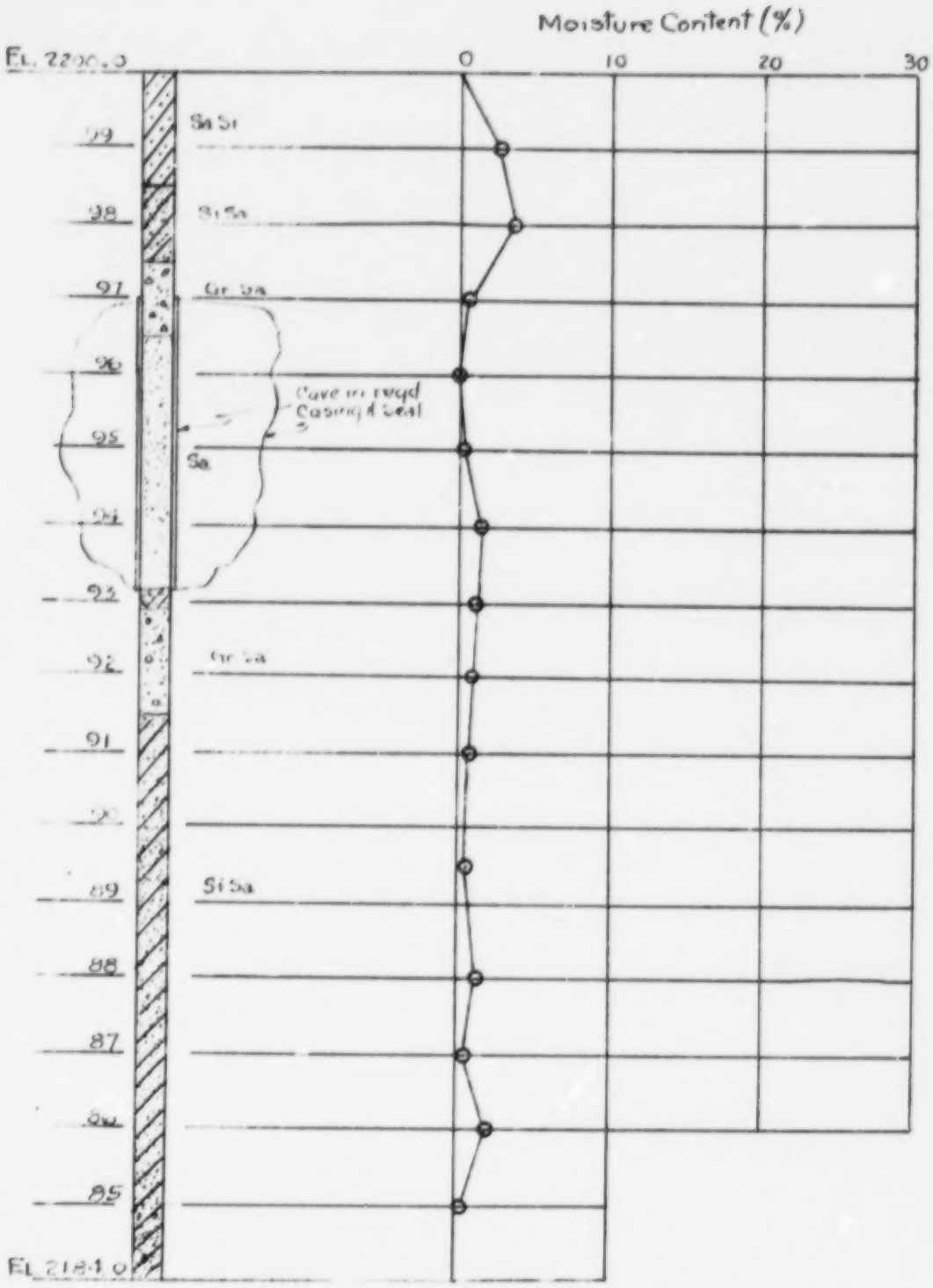


Figure 3.20 - Soil Boring - PB-1

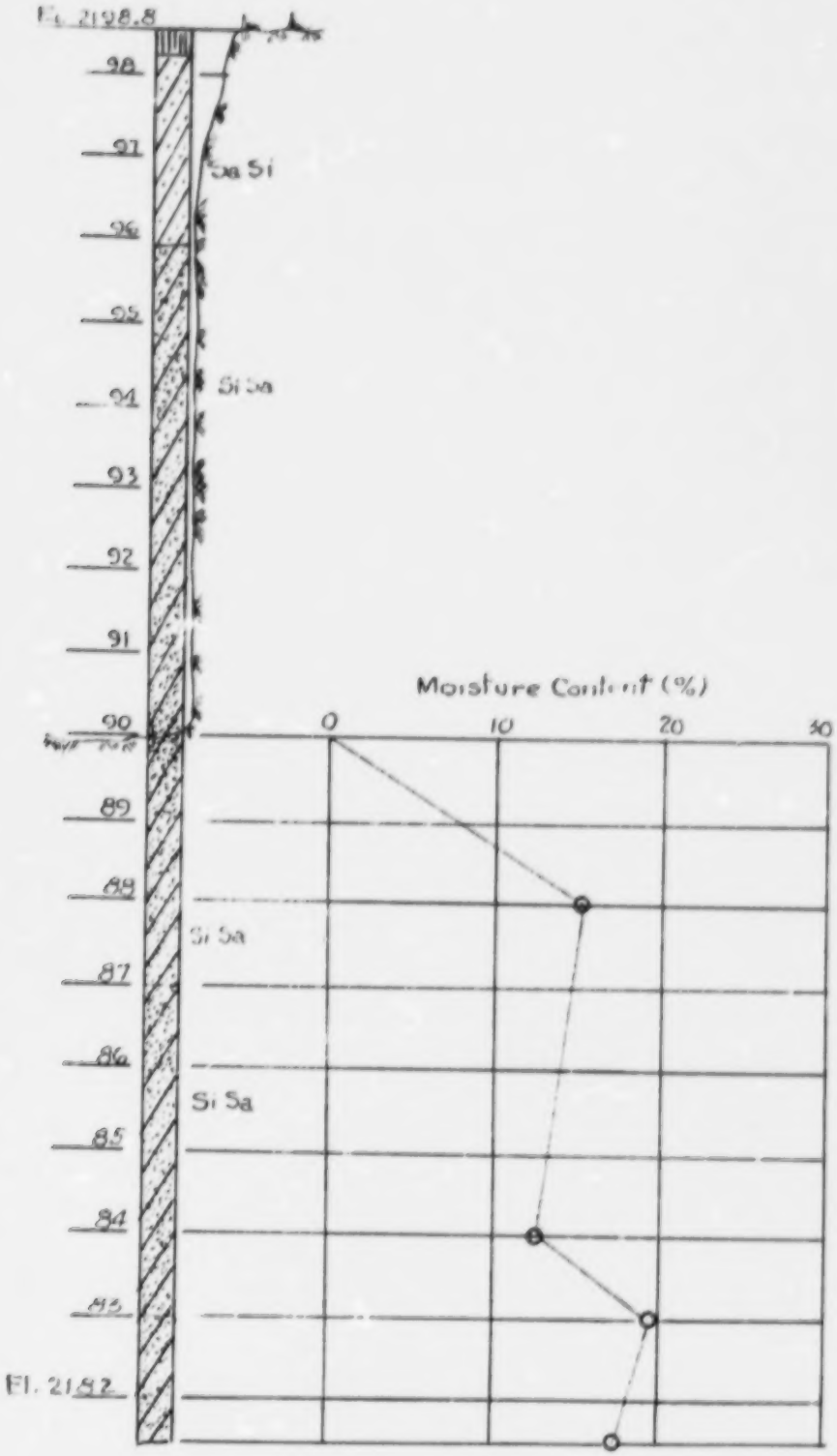


Figure 3.21 - Soil Boring - PB-2

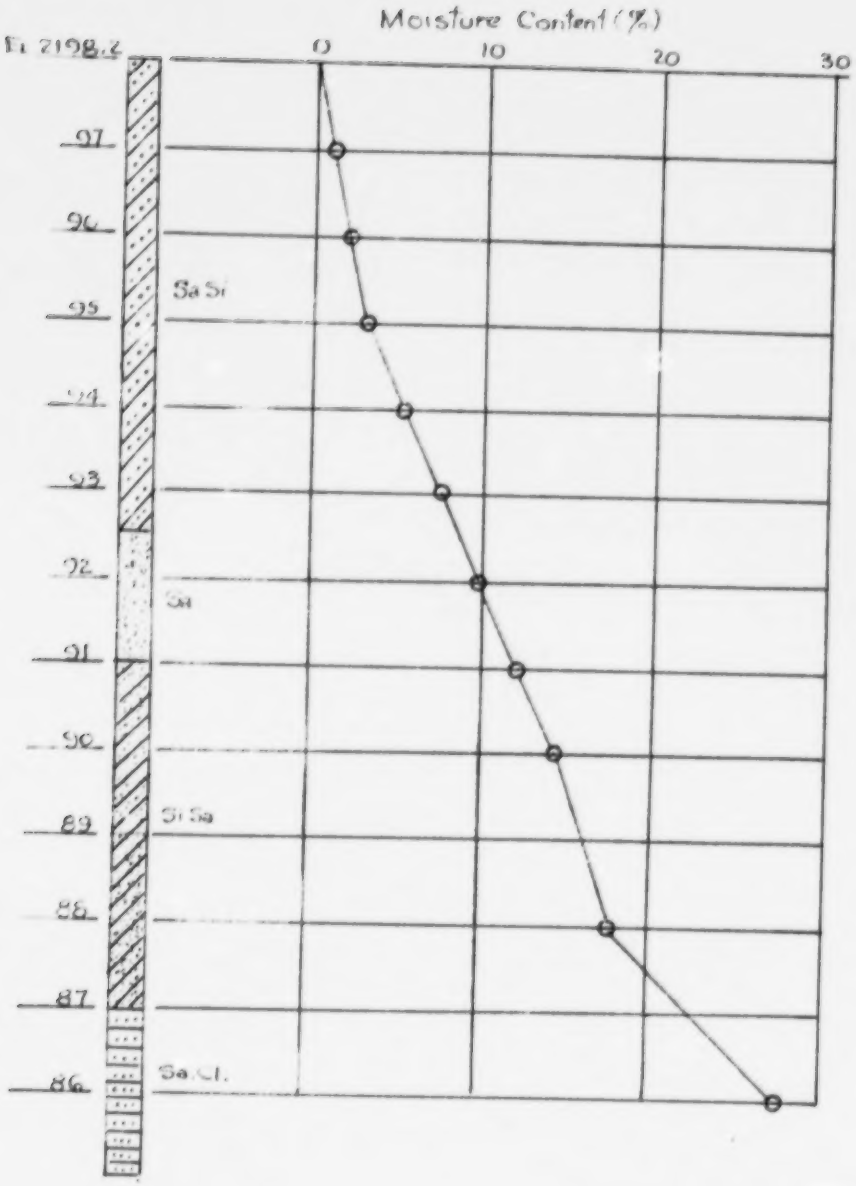


Figure 3.22 - Soil Boring - PB-4

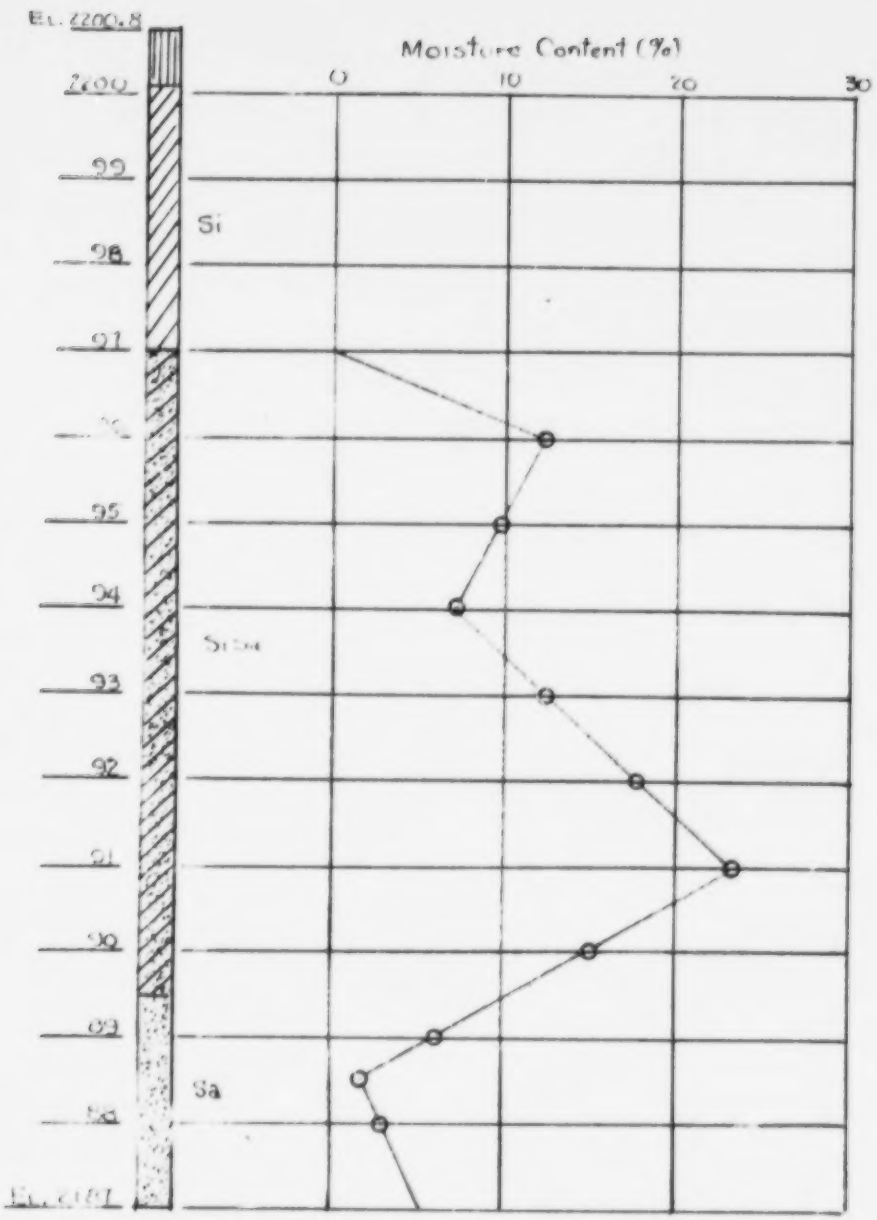


Figure 3.23 - Soil Boring - PB-5

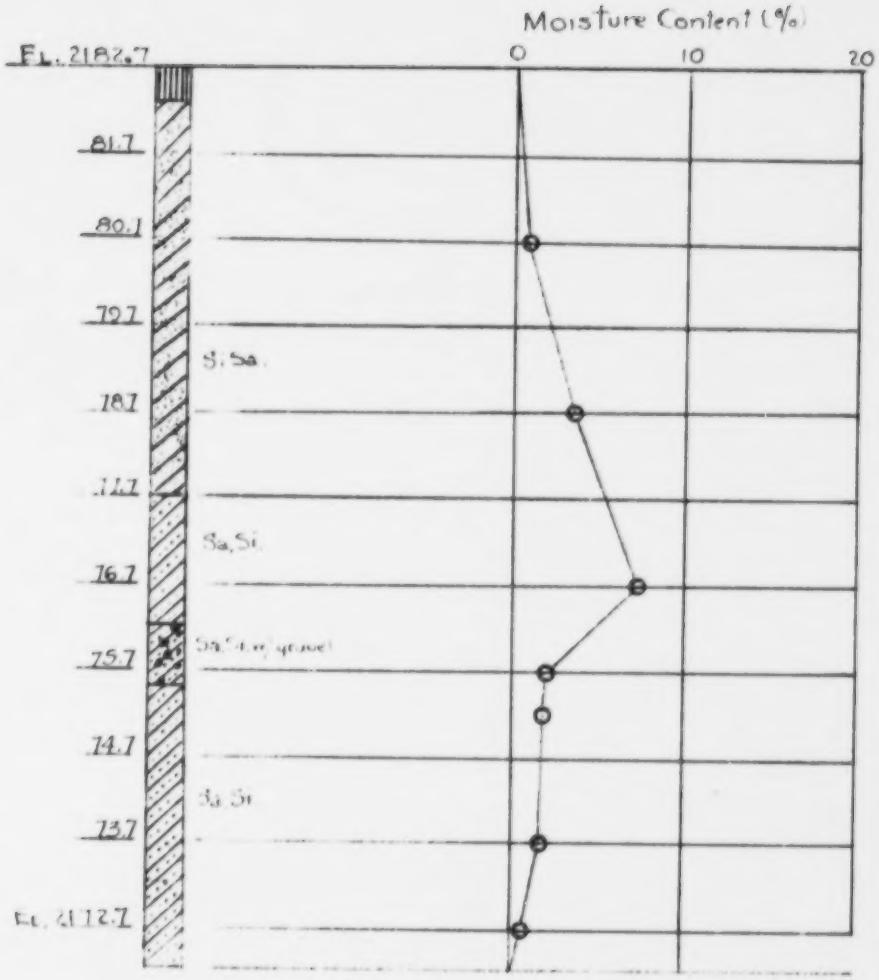


Figure 3.24 - Soil Boring - PB-6

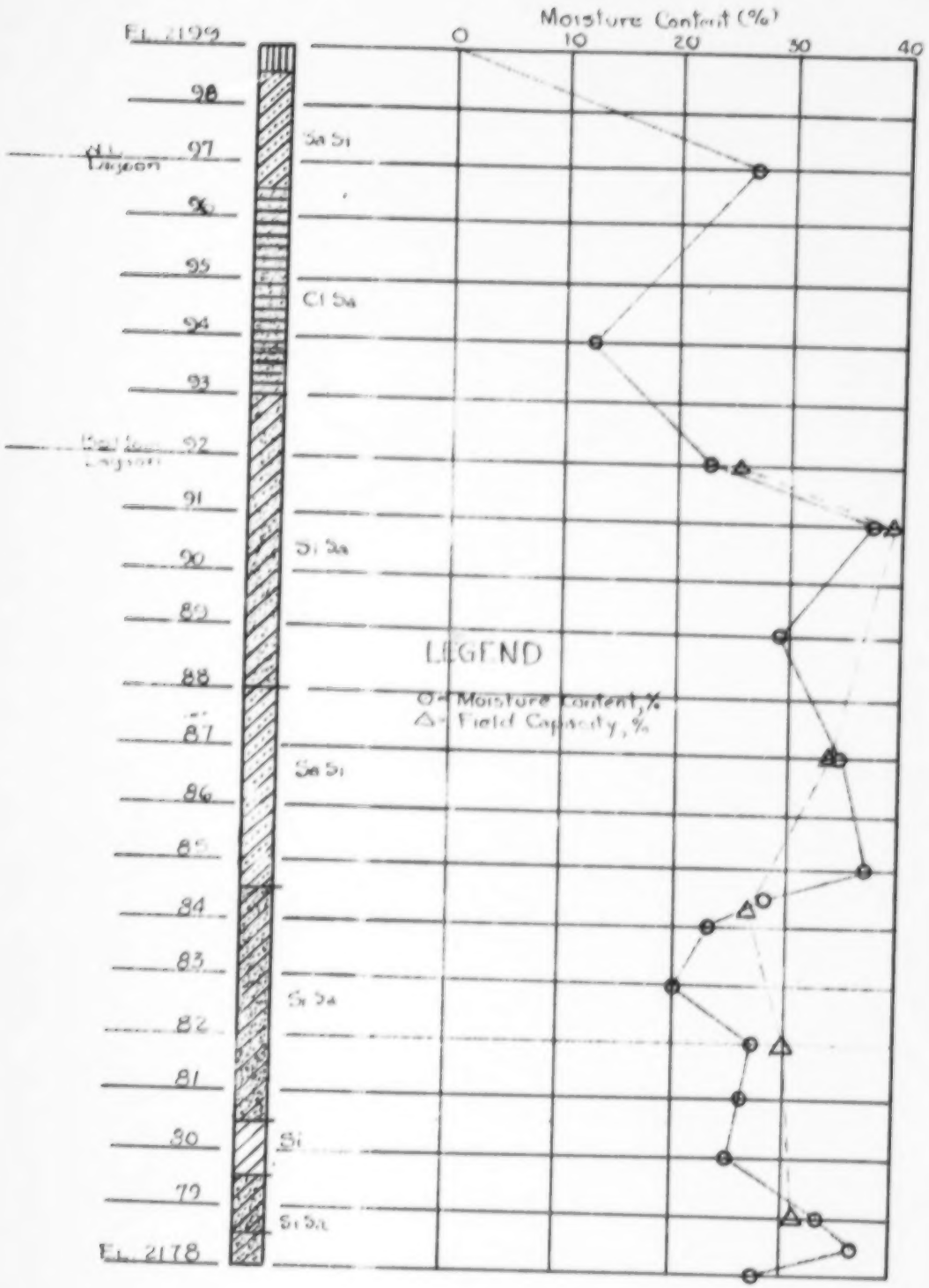


Figure 3.25 - Soil Boring - PB-7.

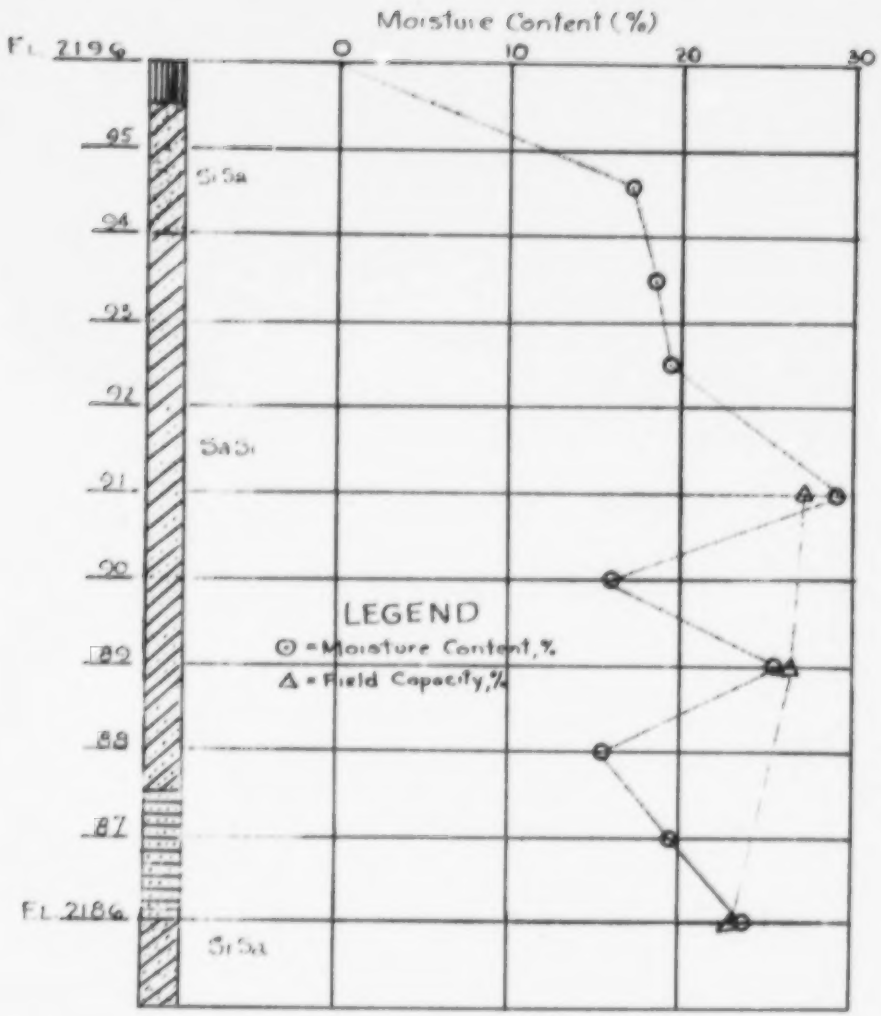


Figure 3.26 - Soil Boring - PB-8

3.3.5 Discussion

As previously indicated, a true hydrologic analysis requires that a balance must exist between the quantity of water supplied and the quantity leaving a receiving basin. The data presented in Tables 3.2 to 3.5 inclusive, indicate that a reasonable evaluation of each of the hydrologic factors has been accomplished. Percentages by which the calculated influent and effluent values differed from the values obtained by direct measurement are compatible with the recognized limits of accuracy of the field measurements which were used as the basis for comparison.

Coefficients of permeability resulting from this series of observations varied significantly from those determined in the laboratory prior to construction of the lagoons. A comparison of these values is presented as follows:

Location	Coefficient of Permeability				
	U. of A. Laboratory			Method "X"	Std. Test
	*	**	***		
East Lagoon	0.085	0.0195	0.0195	0.0034	-
West Lagoon	0.085	0.0195	0.0195	0.0014	0.0012

* Soil received 95% compaction - no additive.

** 1/2 of 1% by weight of bentonite added to the 95% compacted soil.

*** 1/2 of 1% by weight of Portland cement added to the 95% compacted soil.

The low values observed during this study would seem to demonstrate the self-sealing potential of lagoons of this type when constructed in fine

self-sealing potential of lagoons of this type when constructed in fine sandy silt soils. The higher coefficient observed in the east lagoon probably resulted from a combination of the effects of the following factors:

1. The presence of sand covering a majority of the bottom area. (See Appendix A and Figure 1.2).
2. Differing lengths of time during which the lagoons have been in operation.
3. Different types of sewage flowing into the two lagoons. The west lagoon has received raw sewage for the majority of its operational existence, while the east lagoon has received west lagoon effluent for the majority of its operation.

Baver[26] found that organic material has effects on percolation and aids aggregation of particles in soils. The lower coefficient of permeability observed for the west lagoon, when considered in conjunction with the results of volatile matter determinations presented in Figure 3.17 would seem to substantiate this observation. The fact that observed coefficients of permeability increased with depth while volatile matter content decreased with depth, further confirms the apparent existence of a relationship between the coefficient of permeability and percent volatile matter in soils extracted from raw sewage lagoons.

Soil borings designated as PB-7 and PB-8 were selected for interpretation of moisture content of representative soil samples extracted from the study site. A comparison of the moisture content and the field capacity values for soil samples extracted from various depths within each boring is presented in Figures 3.25 and 3.26. It may be concluded from the slight differences observed that successive soil horizons were devoid of gravity water, with only capillary water remain-

ing and defining an unsaturated soil condition. As indicated previously, this condition may be attributed to the ability of the benthal blanket to minimize penetration and retard water.

4. OPERATIONAL DATA

4.1 GENERAL

Collection of engineering data was initiated as soon as waste-water was introduced into the west pond and a satisfactory growth of algae was observed. Since the pond site was completed prior to completion of the outfall line, initial influent was hauled to the site by tank truck. Predetermined volumes of truck tanks served as the basis for flow measurement until the influent pipe and flume were installed. At that time continuous stage measurement was initiated as described in Section 3.3.2.

Initial indications that seepage and evaporation exceeded influent flow delayed effluent flow measurement until March, 1962. Since operational data accumulated during the period of measurable effluent flow was considered to be more representative of normal operating conditions, the more detailed discussion of operational characteristics of the pond will be limited to this period.

4.2 CHEMICAL AND BIOLOGICAL DATA

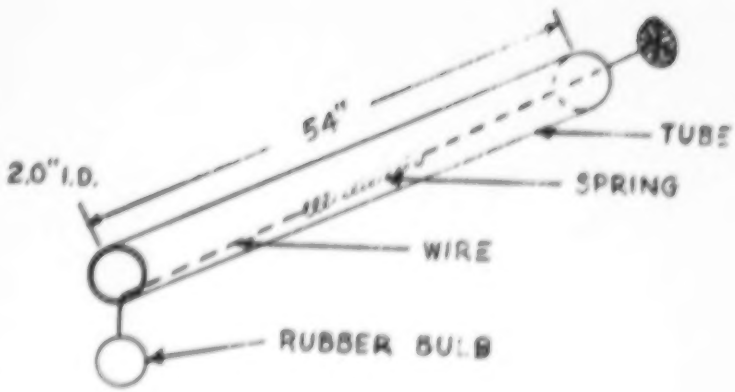
Dissolved oxygen, temperature, and pH observations were begun in September, 1960. It was felt that these observations would provide some indication of changing operational conditions which were expected to occur. Since previous investigations had indicated that these parameters were subject to diurnal variations, 2:00 p.m. was selected as the time at which optimum values might be expected, a fact which was later confirmed. (See Figure 3.1). Initially,

sampling was limited to surface samples taken at Stations 3, 6 and 9, which are identified in Figure 4.1. Samples were collected three days per week on Monday, Wednesday, and Friday.

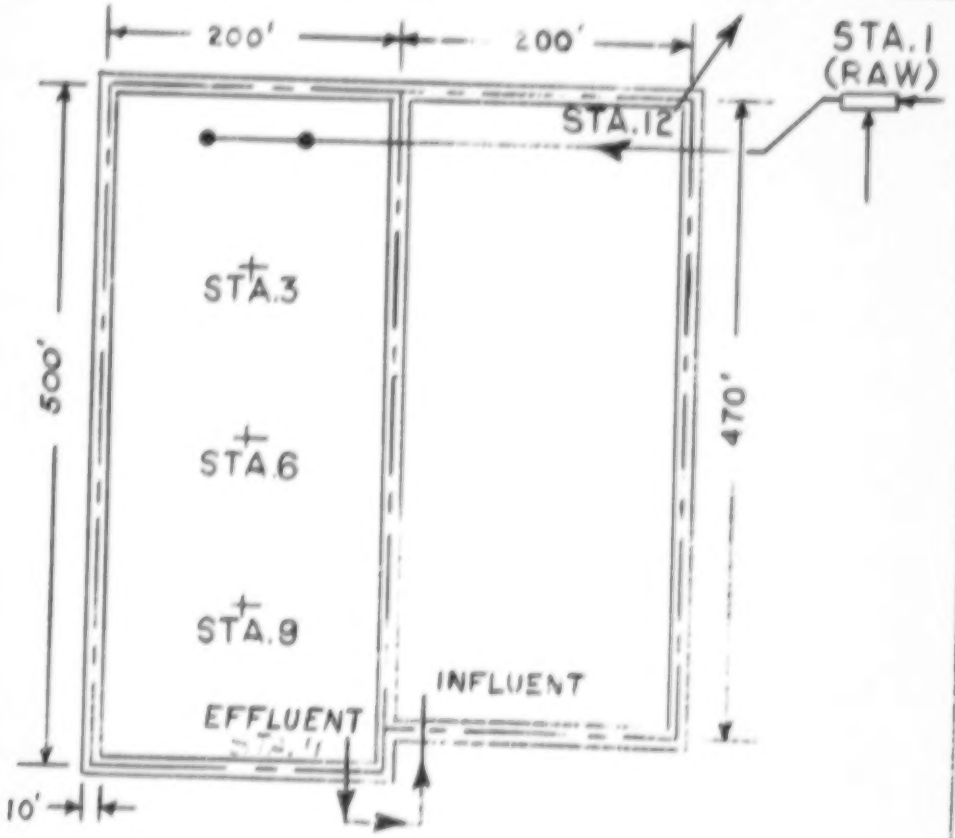
This schedule was followed with unavoidable interruptions until July, 1961, at which time bottom samples were added. Results of these operations are presented in Figures 4.2 to 4.7 inclusive.

Although intensive sampling periods of 24-hour duration were initiated in April, 1961, it was not felt that influent flow was of sufficient magnitude to justify continuation of a regular intensive sample schedule until September 1961. Following this date, at least one intensive sampling period was scheduled each month. During each 24-hour sampling period, samples were collected hourly and influent and effluent samples were added to the top and bottom samples taken at Stations 3, 6, and 9.

It is felt that Figures 3.1 and 3.2 present representative composite dissolved oxygen, temperature, and pH data for the study pond during a period of reasonably high loading conditions. Detailed chemical and biological data accumulated during the same period of time are presented in Table 4.1. Biochemical oxygen demand data accumulated during the entire study period is presented in Table 4.2. Hourly alkalinity and carbon dioxide data accumulated during the 24-hour sampling periods conducted during the June 11 to July 30, 1962, time interval are included as a part of Appendix B. It should be emphasized that the carbon dioxide data was extrapolated from previously prepared nomographs as distinguished from direct laboratory analysis. Extrapolation was necessary since the total solids content of the waste-water was excessive.



REPRESENTATIVE SAMPLER



SAMPLING STATIONS

Fig. 4.1

STATION 3

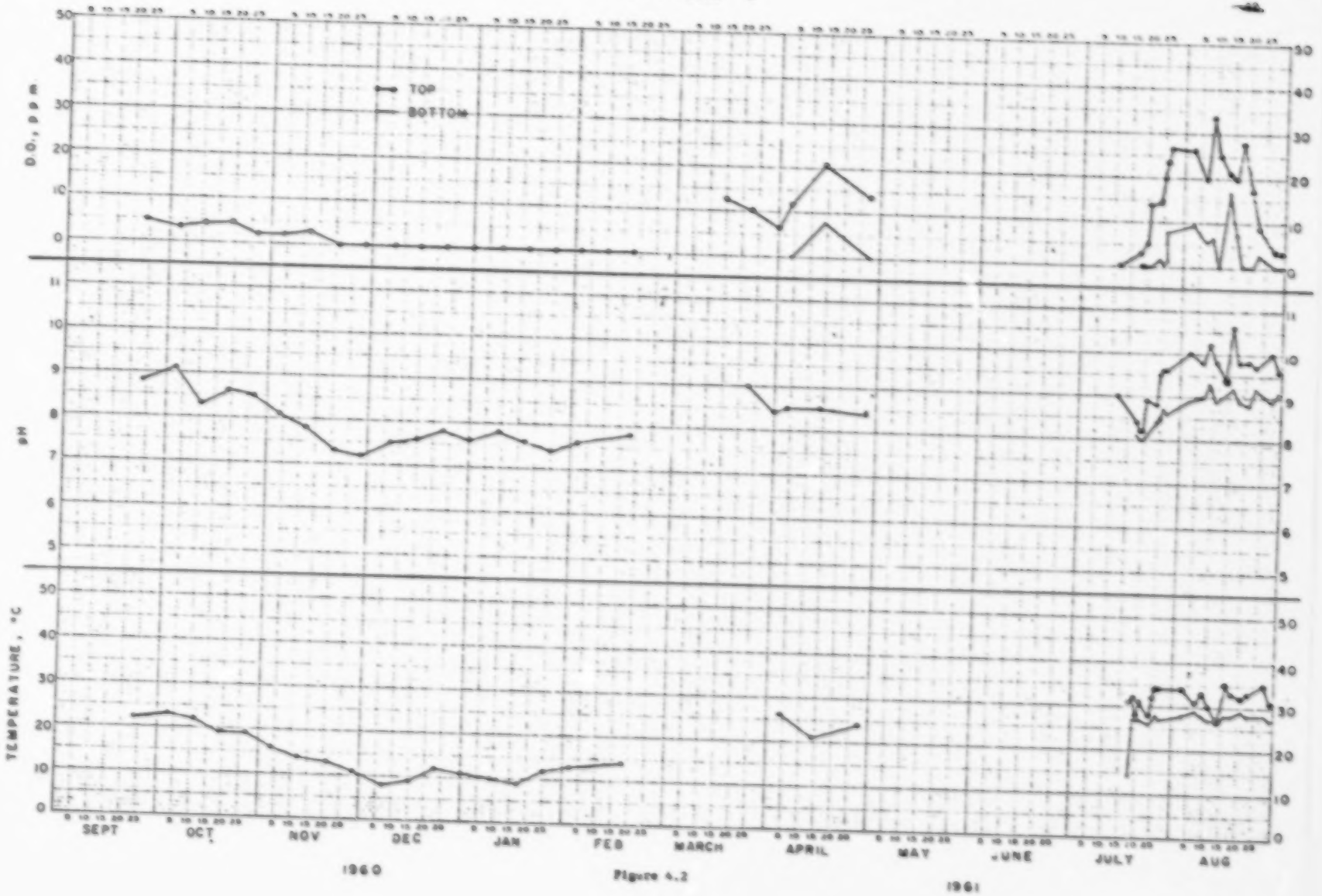


Figure 4.2

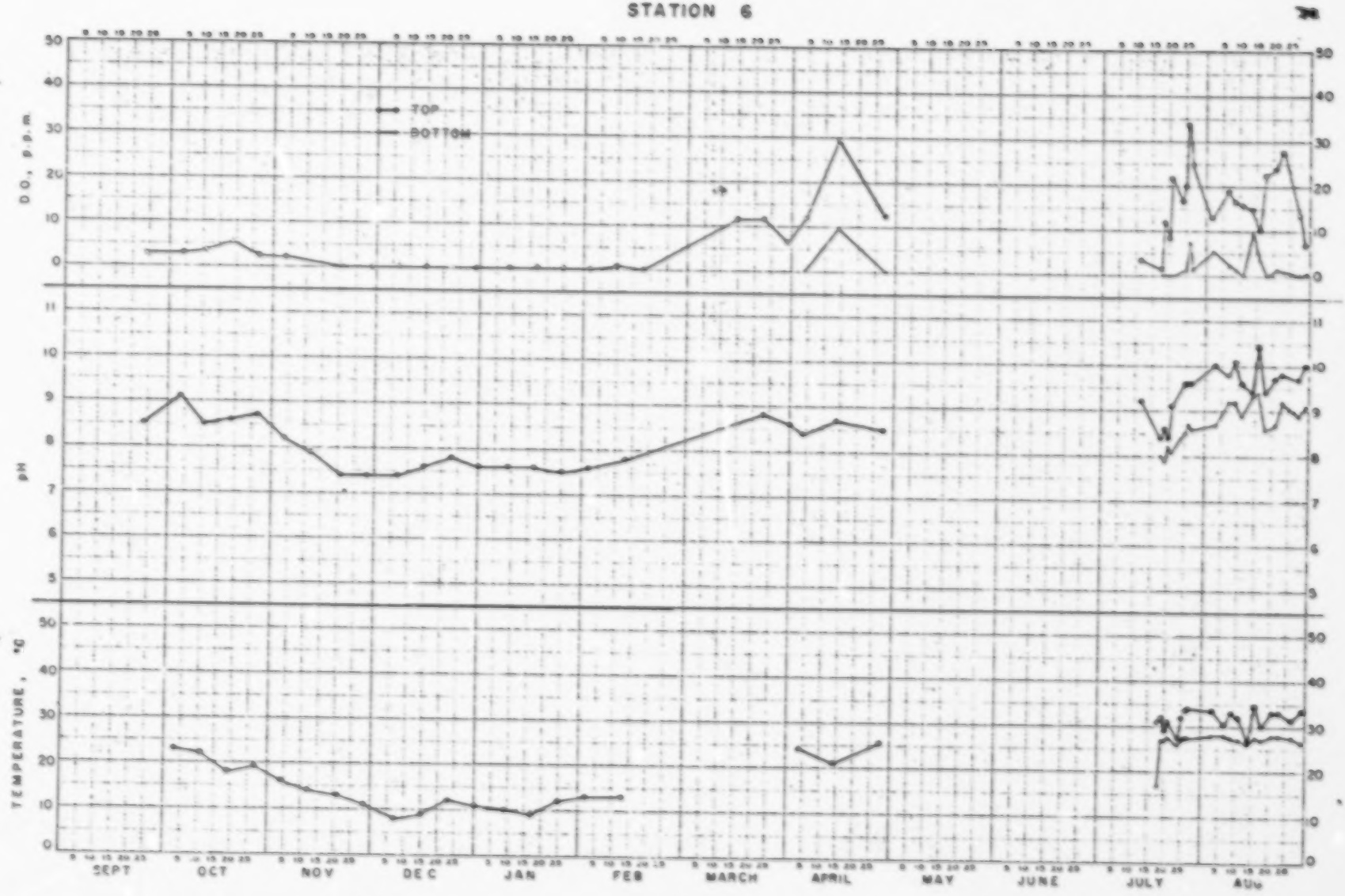

STATION 6
TOP
BOTTOM
DO, p.p.m.
pH
TEMPERATURE, °C
SEPT
OCT
NOV
DEC
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
AUG
1960
1961

Figure 4.3

STATION 9

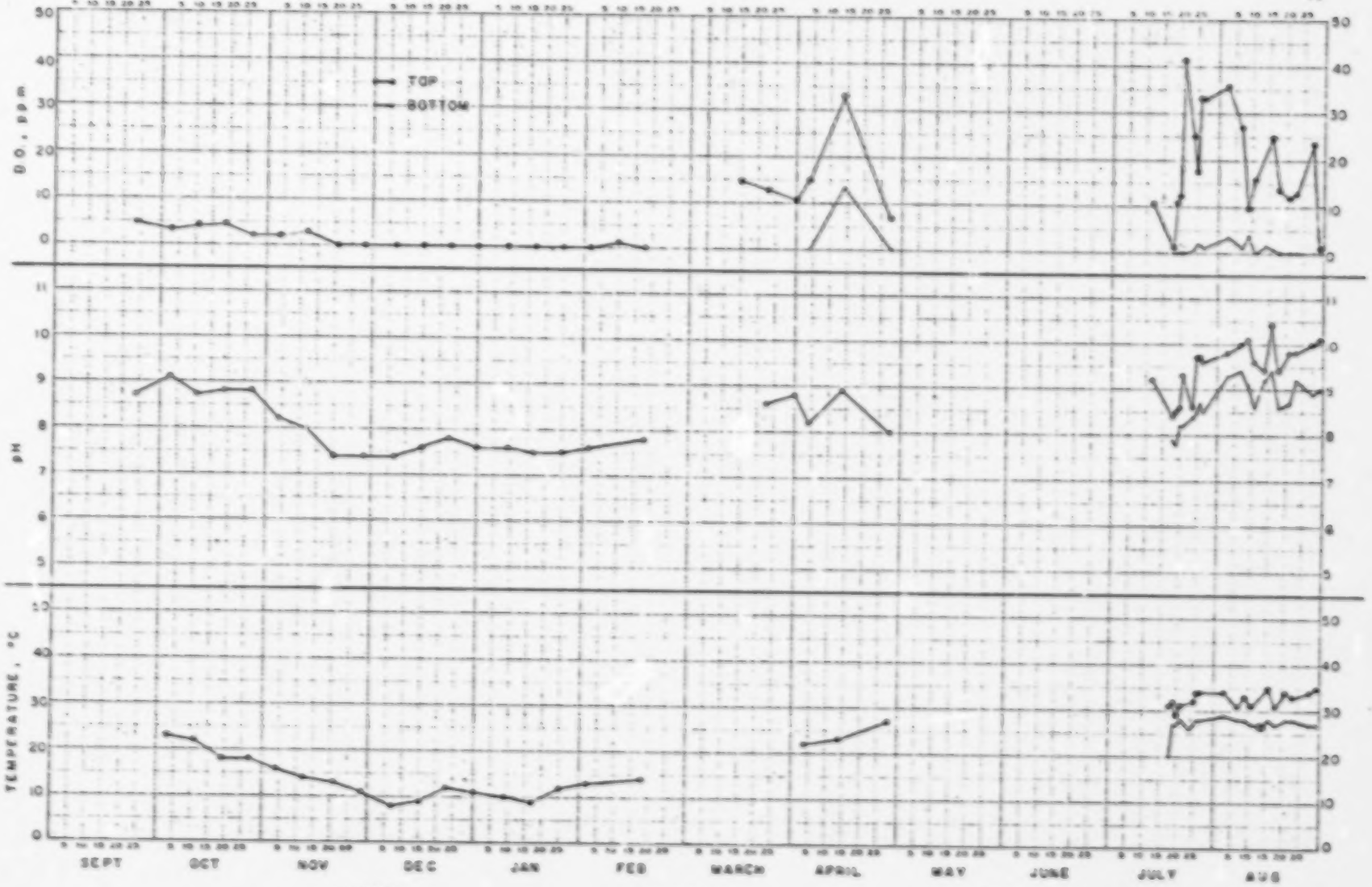


Figure 4.4

STATION 3

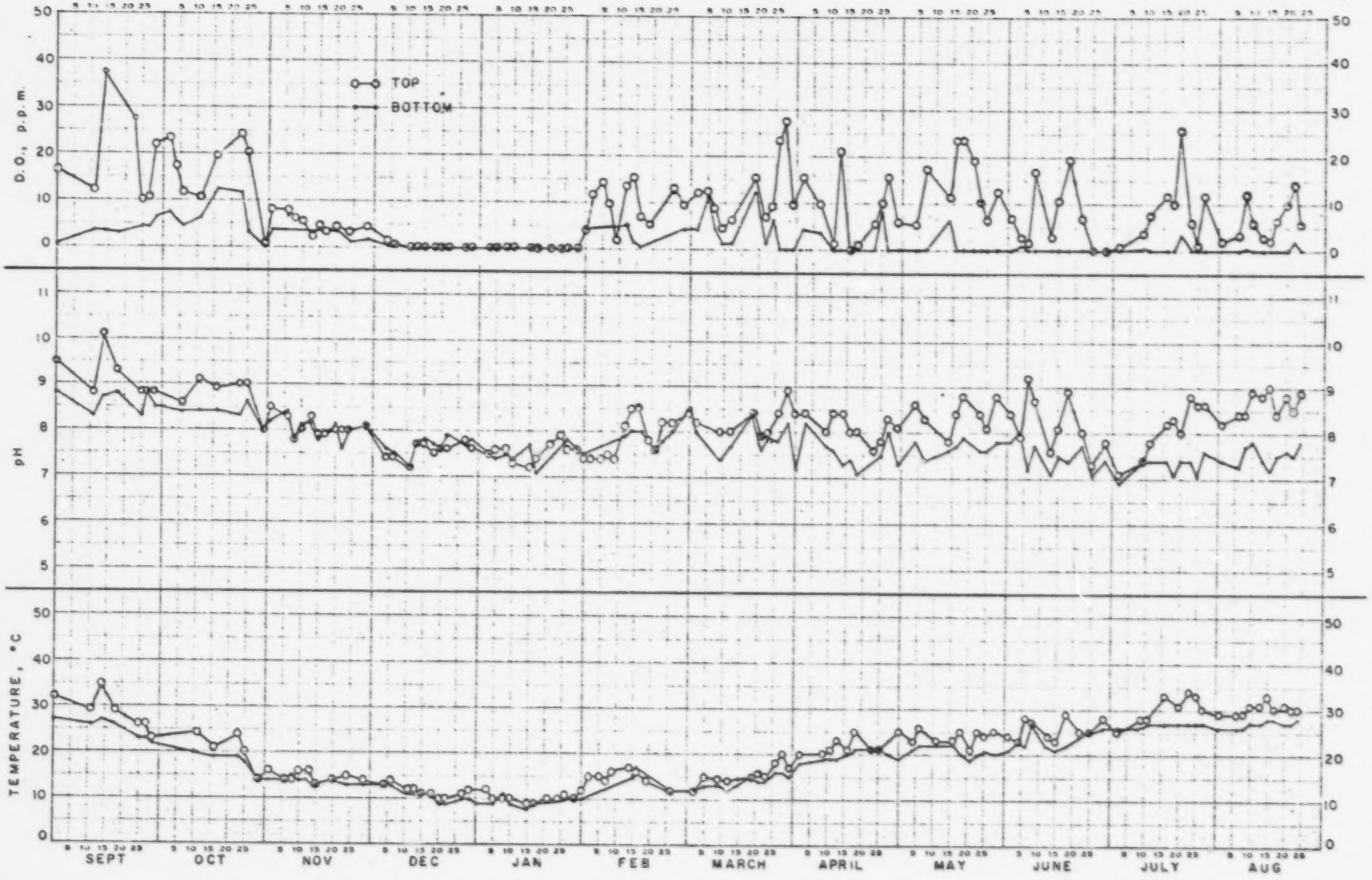


Figure 4.5

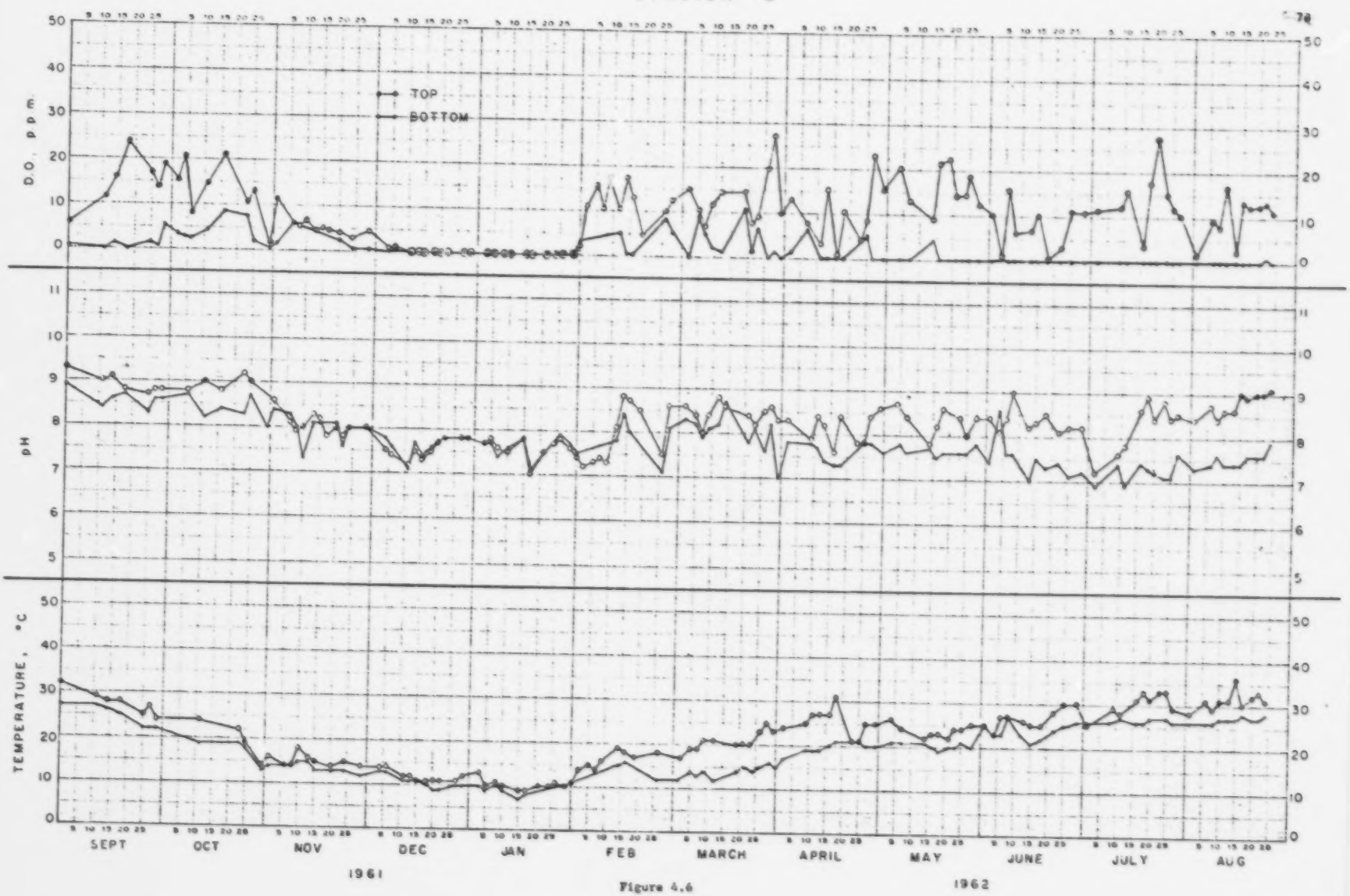

STATION 6
D.O. ppm
TOP
BOTTOM
pH
TEMPERATURE, °C
SEPT
OCT
NOV
DEC
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
AUG
1961
1962

Figure 4.6

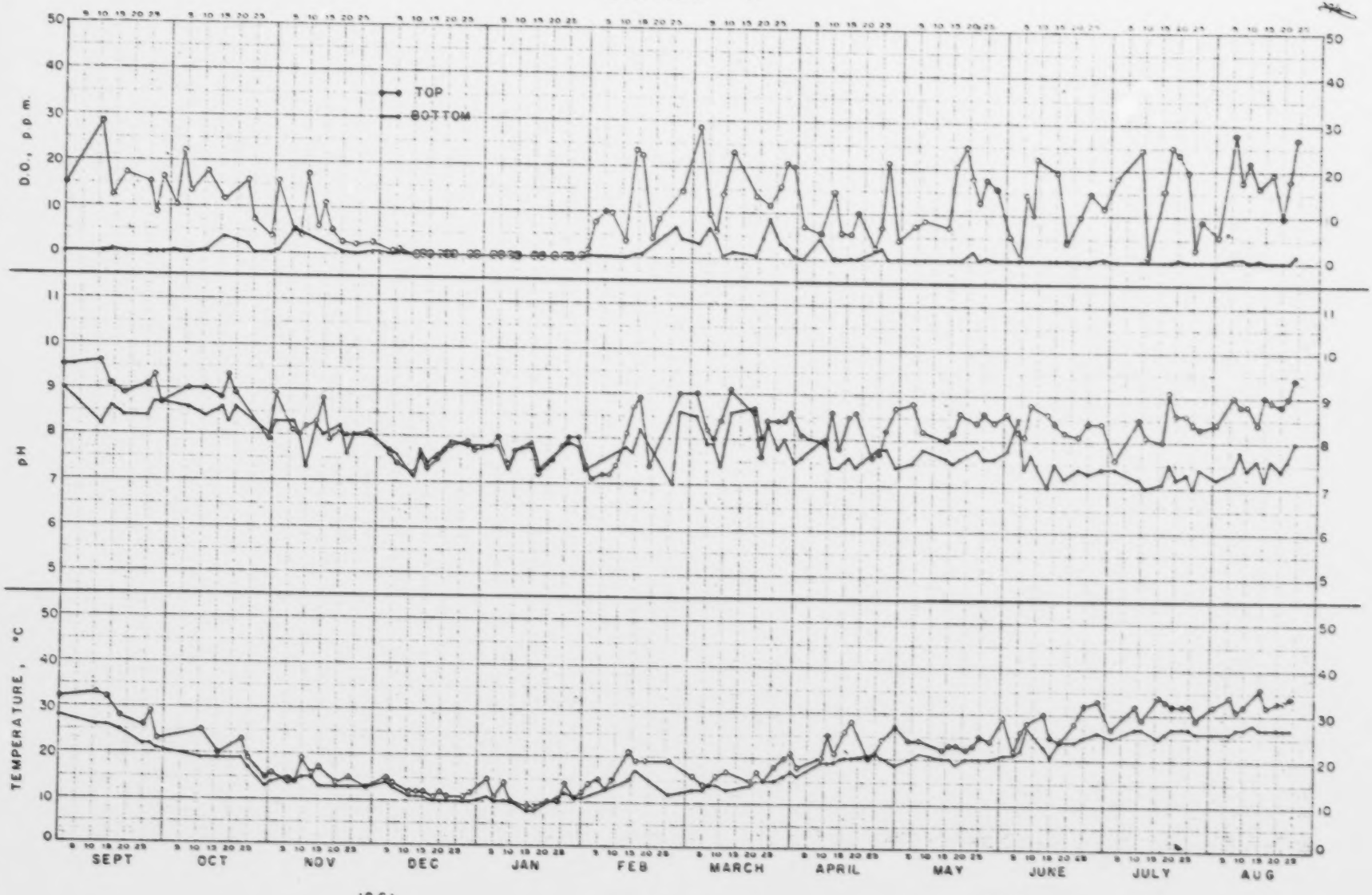

STATION 9
DO, ppm
TOP
BOTTOM
pH
TEMPERATURE, °C
SEPT
OCT
NOV
DEC
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
AUG
1961
1962

Figure 4.7

Table 4.1

CHEMICAL AND BIOLOGICAL DATA

Test Station	Chlorides (ppm)	NO_2-NO_3 (asN) (ppm)	NH_3-N (ppm)	Org.-N (ppm)	Total N (ppm)	SO_4 (ppm)	Total PO_4 (ppm)	T.S. (ppm)	BOD (ppm)	COD (ppm)
		SAMPLING PERIOD: June 11 and 12, 1962 (1200, Monday to 1200, Tuesday)								
1*	69	-	26	21	47	70	50	786	151	640
C**	72	-	17	21	38	88	43	-	-	-
11*	-	-	14	25	39	105	40	903	90	1031
12*	-	-	7	27	34	80	28	-	40	-
		SAMPLING PERIOD: June 19 and 20, 1962 (1200, Tuesday to 1200, Wednesday)								
1	52	0.84	14	18	32	56	112	1062	182	648
C	83	0.75	31	19	50	98	75	878	-	-
11	90	0.65	12	15	27	87	43	854	68	185
12	58	0.65	5	11	16	95	24	843	29	105
		SAMPLING PERIOD: June 27 and 28, 1962 (1200, Wednesday to 1200, Thursday)								
1	45	0.93	29	9	38	70	107	707	85	250
C	39	1.68	12	17	29	80	35	905	-	-
11	51	1.77	11	15	26	90	23	895	28	361
12	47	1.31	6	11	17	95	14	966	17	344
		SAMPLING PERIOD: July 5 and 6, 1962 (1200, Thursday to 1200, Friday)								
1	70	1.03	33	16	49	53	50	952	140	474
C	70	1.21	14	16	30	86	53	850	-	-
11	76	1.21	13	15	28	80	28	898	37	253
12	86	1.21	4	10	14	93	15	869	22	185

(Continued on following page)

Table 4.1 (Continued)

Test Station	Chlorides (ppm)	NO_2-NO_3 (asN) (ppm)	NH_3-N (ppm)	Org.-N (ppm)	Total N (ppm)	SO_4 (ppm)	Total PO_4 (ppm)	T.S. (ppm)	BOD (ppm)	COD (ppm)
		SAMPLING PERIOD: July 13 and 14, 1962 (1200, Friday to 1200, Saturday)								
1	52	1.21	30	8	38	78	43	768	89	202
C	74	1.40	14	20	34	90	34	854	-	-
11	76	1.40	13	17	30	93	31	899	55	297
12	80	0.93	3	10	13	101	7	821	22	170
		SAMPLING PERIOD: July 21 and 22, 1962 (1200, Saturday to 1200, Sunday)								
1	46	5.79	35	15	50	90	40	918	152	437
C	46	2.15	15	22	37	88	35	823	-	-
11	36	1.96	13	21	34	89	33	883	55	356
12	32	1.31	3	10	13	98	8	804	23	211
		SAMPLING PERIOD: July 29 and 30, 1962 (1200, Sunday to 1200, Monday)								
1	109	1.77	33	13	46	101	24	951	117	286
C	70	2.15	16	19	35	93	19	809	-	-
11	50	1.87	13	17	30	91	19	849	38	251
12	50	1.40	7	9	16	95	8	752	22	175

* Aliquots proportional to the depth of flow in the inlet and outlet pipes were composited hourly during the sampling period.

** Equal aliquots of integrated depth samples taken hourly at Stations 3, 6, and 9 were composited during the sampling period.

Table 4.2

Date	STANDARD BOD												PER CENT BOD REDUCTION				
	Raw		Station 3		Station 6		Station 9		Station 11		Station 12		Composite of pond					
	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	From Raw to Station 9 %	From Raw to Station 11 %	From Raw to Station 12 %	From Raw to Composite of pond %	From Station 11 to Station 12 %
3-15-61	132	2	56	1	23	1	35	1	-	-	-	-	-	-	73	-	-	-	-
3-23-61	98	2	31	1	28	1	23	1	-	-	-	-	-	-	76	-	-	-	-
4-4-61	162	4	30	3	38	3	38	3	-	-	-	-	-	-	76	-	-	-	-
4-14-61	153	4	68	3	53	3	62	3	-	-	-	-	-	-	59	-	-	-	-
4-29-61	306	4	124	3	128	3	116	3	-	-	-	-	-	-	62	-	-	-	-
5-29-61	220	4	39	3	43	3	37	3	-	-	-	-	-	-	83	-	-	-	-
7-3-61	196	2	-	-	-	-	-	-	-	-	-	-	76	5	-	-	-	61	-
7-19-61	175	2	-	-	-	-	-	-	-	-	-	-	67	5	-	-	-	62	-
7-27-61	147	2	-	-	-	-	-	-	-	-	-	-	71	5	-	-	-	52	-
8-3-61	213	2	-	-	-	-	-	-	-	-	-	-	62	5	-	-	-	71	-
8-9-61	193	2	-	-	-	-	-	-	-	-	-	-	47	5	-	-	-	76	-
8-14-61	154	2	-	-	-	-	-	-	-	-	-	-	36	5	-	-	-	77	-
8-23-61	179	2	-	-	-	-	-	-	-	-	-	-	51	5	-	-	-	72	-
9-6-61	100	4	17	3	14	3	14	3	-	-	-	-	-	-	86	-	-	-	-
9-20-61	108	4	11	3	13	3	16	3	-	-	-	-	-	-	85	-	-	-	-
10-12-61	115	4	20	3	16	3	15	3	-	-	-	-	-	-	87	-	-	-	-
10-26-61	92	4	12	3	11	3	13	3	-	-	-	-	-	-	86	-	-	-	-
11-16-61	176	4	47	3	46	3	43	3	-	-	-	-	-	-	76	-	-	-	-
12-7-61	193	4	110	3	112	3	100	3	-	-	-	-	-	-	48	-	-	-	-
1-19-62	186	4	107	3	97	3	95	3	-	-	-	-	-	-	49	-	-	-	-
2-22-62	165	4	33	3	35	3	36	3	-	-	-	-	-	-	78	-	-	-	-
3-15-62	243	4	35	3	47	3	35	3	-	-	-	-	-	-	86	-	-	-	-
4-5-62	294	4	80	3	79	3	92	3	-	-	-	-	-	-	68	-	-	-	-
5-11-62	250	4	93	3	68	3	79	3	88	6	96	6	-	-	68	65	61	-	Increase 9
6-11-62	151	4	88	3	68	3	74	3	90	6	40	6	-	-	51	40	74	-	56
6-19-62	182	4	82	3	81	3	67	3	68	6	29	6	-	-	63	63	84	-	57

(Continued on following page)

Table 4.2 (Continued)

Date *	STANDARD BOD												PER CENT BOD REDUCTION				
	Raw		Station 3		Station 6		Station 9		Station 11		Station 12		Composite of pond					
	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	BOD	Sample Type	From Raw to Station 9 %	From Raw to Station 11 %	From Raw to Station 12 %	From Raw to Composite of pond %	From Station 11 to Station 12 %
6-27-62	85	4	38	3	41	3	28	3	28	3	17	6	-	-	67	67	80	-	39
7-5-62	140	4	32	3	30	3	26	3	37	6	22	6	-	-	81	74	94	-	40
7-13-62	89	4	35	3	30	3	35	3	55	6	22	6	-	-	61	38	75	-	60
7-21-62	152	4	46	3	43	3	42	3	55	6	23	6	-	-	72	64	84	-	58
7-29-62	117	4	41	3	41	3	37	3	38	6	22	6	-	-	68	68	81	-	42

* Date recorded is starting date where data represents a period of intensive sampling.

Types of Samples:

1. Samples were taken at indicated station at mid-depth using a standard dissolved oxygen sampler. Samples were grab samples taken at approximately 2:00 p.m.

2. Grab samples taken from inlet flume. Samples were taken at approximately 2:00 p.m.

3. Samples were gathered by means of a 5 foot tube which allowed a representative sample extending from the surface to the bottom of the pond to be taken. Equal aliquots from each station were composited in large containers corresponding to the various stations. Thus, a composite sample representing each station was collected over the duration of the sampling period.

4. An aliquot proportional to the depth of flow at the intake flume was composited during the sampling period.

5. A tube sample was taken at each station and equal amounts from each station were mixed, yielding a sample representative of the three stations over their entire depth. Samples were taken at approximately 2:00 p.m.

6. Samples were taken at the locations indicated and composited during the sampling period.

4.3 OPERATIONAL EFFICIENCY

Waste-water treatment facilities are commonly evaluated by their ability to remove, by biochemical processes, the undesirable organic and inorganic fractions of the incoming waste-water. The commonly accepted laboratory determination used in making this evaluation is the procedure for determining the biochemical oxygen demand (BOD). A comparison of the BOD of the raw sewage entering a lagoon with that of the flow at any preselected point within the same facility should provide some measure of the changes imposed by the intervening stabilization processes. This type of information is provided in Table 4.2. It should be noted that BOD reduction accomplished between Stations 1 and 9 seemed to follow somewhat of a seasonal pattern, with the lower values occurring during the winter months. A downward trend in removal percentages seems to be indicated. Removal percentages between Station 1 and Station 11 compare favorably with these values; however, both groups of values are below those generally expected from an installation of this type. As would be expected, the removal efficiency within the second pond is less than that observed in the first pond. With the exception of one value, overall efficiencies for the two ponds operating in series ranged from 74% to 84% during June and July, 1962.

Two additional parameters which must be considered when evaluating the efficiency of a stabilization pond are BOD loading and retention time. Representative BOD loadings shown in Table 4.3 varied from 28 to 75 pounds per acre per day during the period for which efficiences were discussed. During this same period retention times were approximately 30 days (see Table 3.1).

Table 4.3

BOD LOADING

Date	Influent Flow (Gal.)	Influent BOD (ppm)	BOD LOADING (lb/acre/day)
4/14/61	18,785	153	12
4/29/61	19,425	306	25
5/29/61	21,840	220	20
7/19/61	39,403	175	25
7/27/61	26,126	147	16
10/26/61	62,355	92	24
11/16/61	60,000	176	44
12/7/61	45,800	193	37
2/22/62	50,560	165	35
3/15/62	64,700	243	66
4/5/62	65,100	294	80
6/11/62	101,584	151	64
6/19/62	95,644	182	73
6/27/62	77,346	85	28
7/5/62	75,094	140	44
7/13/62	99,767	89	37
7/21/62	117,930	152	75
7/29/62	125,524	117	61

4.4 DISCUSSION

Long-term dissolved oxygen and pH sampling data accumulated from points near the top and bottom of the pond in the vicinity of the three interior sampling stations show very similar trends when compared on a monthly basis. As might be anticipated, the minimum differences were observed during the two months of lowest temperatures. Bottom samples provided the smallest fluctuations, while the heavily algae-laden surface samples provided the maximum fluctuations. Surface samples taken at Stations 6 and 9 seemed to have the greatest preponderance of dissolved oxygen values in excess of 10. This is not an unusual observation since Station 3 is nearest the inlet structure. The December-January period during which lowest values were observed coincided with the period during which lowest operational efficiency values were recorded.

Vertical temperature differentials observed during the course of the investigation raised some question as to whether severe short circuiting was occurring throughout the pond. As indicated previously (see Section 3.2.3), a tracer study using water soluble fluorescein was conducted on August 10, 1962. Dye introduced into the pond at 1620 first appeared on the surface, made visible by sunlight, over the influent structure at 1627. This visible dye was dissipated within a short period of time by an 8 to 10 mile-per-hour wind blowing out of the northwest. Approximately 2-1/4 hours later, at 1830, all composite samples taken at quarter points located on transverse lines containing the interior sample stations were positive. Surface samples taken at the same points were negative. Composite samples taken near the effluent pipe were negative until 2015, or approximately 4 hours after the

dye was introduced into the pond. All surface samples accumulated throughout the pond continued to be negative at this time. Beginning at 1930, surface samples near the effluent pipe were taken at approximately half-hour intervals. Sampling results continued to be negative until approximately 2245, only 6-1/2 hours after the dye had been introduced. Although no temperature data was accumulated during the tracer study, this time coincided with the time at which top and bottom samples reached the same temperature during the intensive sampling period of July 29-30, 1962. It would seem that some basis had been established for anticipating rather severe temperature gradients accompanied by short circuiting flow patterns during this season of the year.

5. CONCLUSIONS AND RECOMMENDATIONS

1. E. histolytica, T. saginata, and Giardia lamblia, the pathogens of interest in this study, were not found in sufficient supply in natural sources in the Tucson area, therefore extensive field investigations using naturally occurring organisms were not possible. Although attempts to culture E. histolytica in the laboratory, using recognized techniques, provided enough viable cysts for laboratory scale studies, it was not found possible to obtain these cysts in predictable quantities large enough to obtain the desired field information. Until such time as culturing techniques are developed which will insure a statistically reliable production of an abundant supply of cysts, the future success of large scale field investigations is doubtful. Field investigations using suspended particles of the same size and density as the cysts, could conceivably provide valuable information concerning the potential movement of the actual cysts through the pond environment. Until such time as the production of an abundant supply of cysts is possible, studies related to establishing the tolerance of the three organisms to various environmental factors existing in sewage ponds will need to be conducted in the laboratory.

2. As a result of the potential existence of short circuiting, as discussed in Section 4.4., it is conceivable that any pathogenic organisms possessing sufficient tolerance to the pond environment to survive for the flow through time involved, could move through the length of the pond within a period of four hours. Factors such as settling rates, agglomeration, rising gas bubbles, and convection currents would reduce this possibility. As indicated in Section 3.2.3, previous investigators

have found that settling rates for the cysts of E. histolytica as well as the eggs of T. saginata, settle at sufficiently slow rates to allow them to travel the length of the pond within the minimum time of four hours. At the end of this period of time, either of the organisms would be in position to flow out with the effluent once temperature stratification begins to break down. This phenomenon would occur once every 24 hours. Chang[27] reported that E. histolytica cysts remain viable in raw sewage for 28 and 6 days at 7° and 25° centrigrade respectively. It is therefore conceivable that these cysts would be viable when discharged from the pond.

Further studies concerning the viability of pathogenic organisms in waste-water environments of both field and laboratory scale are strongly recommended. The need for additional studies related to the identification, physiology, and ecology of pathogenic organisms occurring in sewage is recognized.

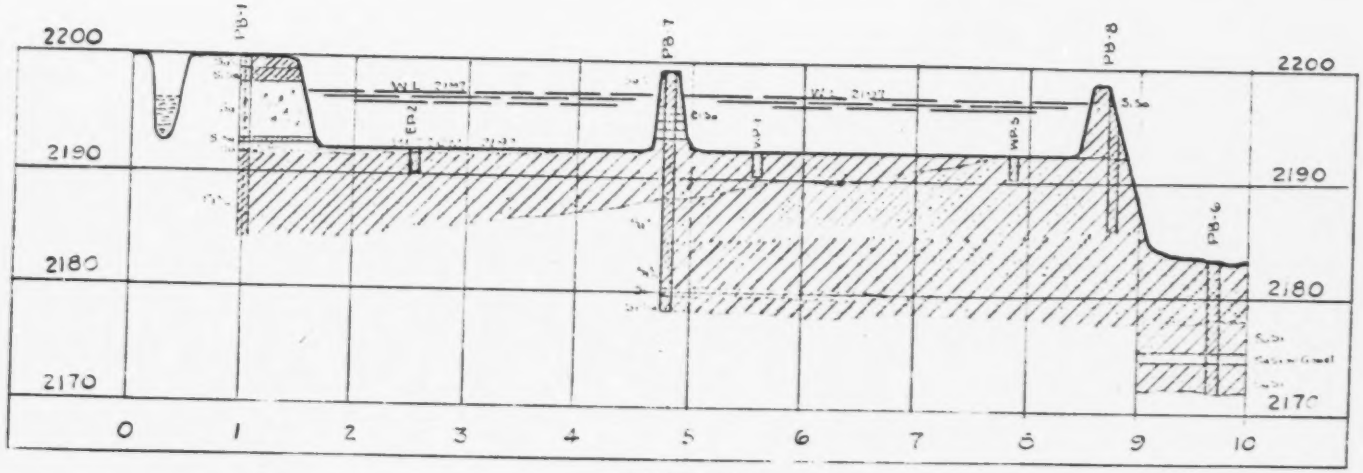
3. Operational data would seem to indicate that ponds of the type investigated are capable of removing only 75% of the BOD loading when this loading approximates 75 pounds per acre of surface area per day and the retention time is 30 days. Although no supporting data were accumulated, it is strongly suspected that the observed short circuiting is, at least in part, responsible for the low removal efficiencies observed. It would therefore follow that a pressing need exists for further investigations related to temperature stratification and density currents existing in stabilization ponds currently existing in the semi-arid southwest.

4. The existence of a natural self-sealing potential was substantiated by the data accumulated from the soil investigations. Coefficients of permeability of the benthal blanket were shown to be less than those of the adjacent and underlying soil increments. They were also shown to be less than the values resulting from laboratory analyses related to soil stabilization prior to construction. Comparisons of field moisture content and field capacity of the soil increments taken from several soil borings demonstrated the unsaturated soil condition adjacent to and below the bottom of the lagoons. This condition illustrates effectively that seepage is appreciably retarded by the benthal blanket.

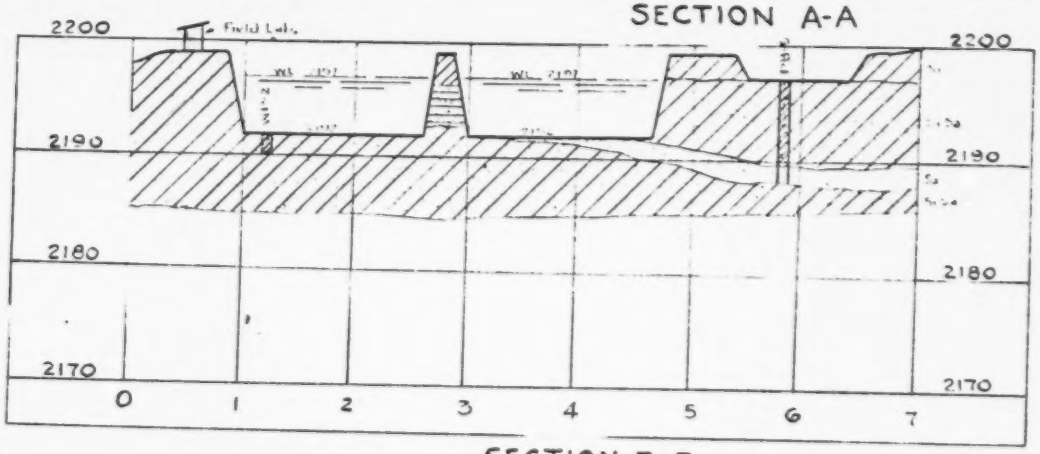
5. Although standard BOD procedures were followed throughout the period of investigation, the effect of algae on these standard tests was of continuing concern. Accumulation of additional information concerning this relationship should be encouraged.

6. The importance of sampling time, when composite sampling is impractical, was demonstrated. When dissolved oxygen and/or pH data is accumulated on the basis of one sample per day, the time at which the sample is taken was shown to be an important factor. Reference to Figure 3.1 illustrates this point. Should these parameters be used as an indication of pond condition, optimum conditions could be expected from 1400 to 1600 while minimal conditions could be expected from 0300 to 0700 during the summer months. Correlation of data from different installations therefore would depend upon similar sampling times.

APPENDIX A



SECTION A-A



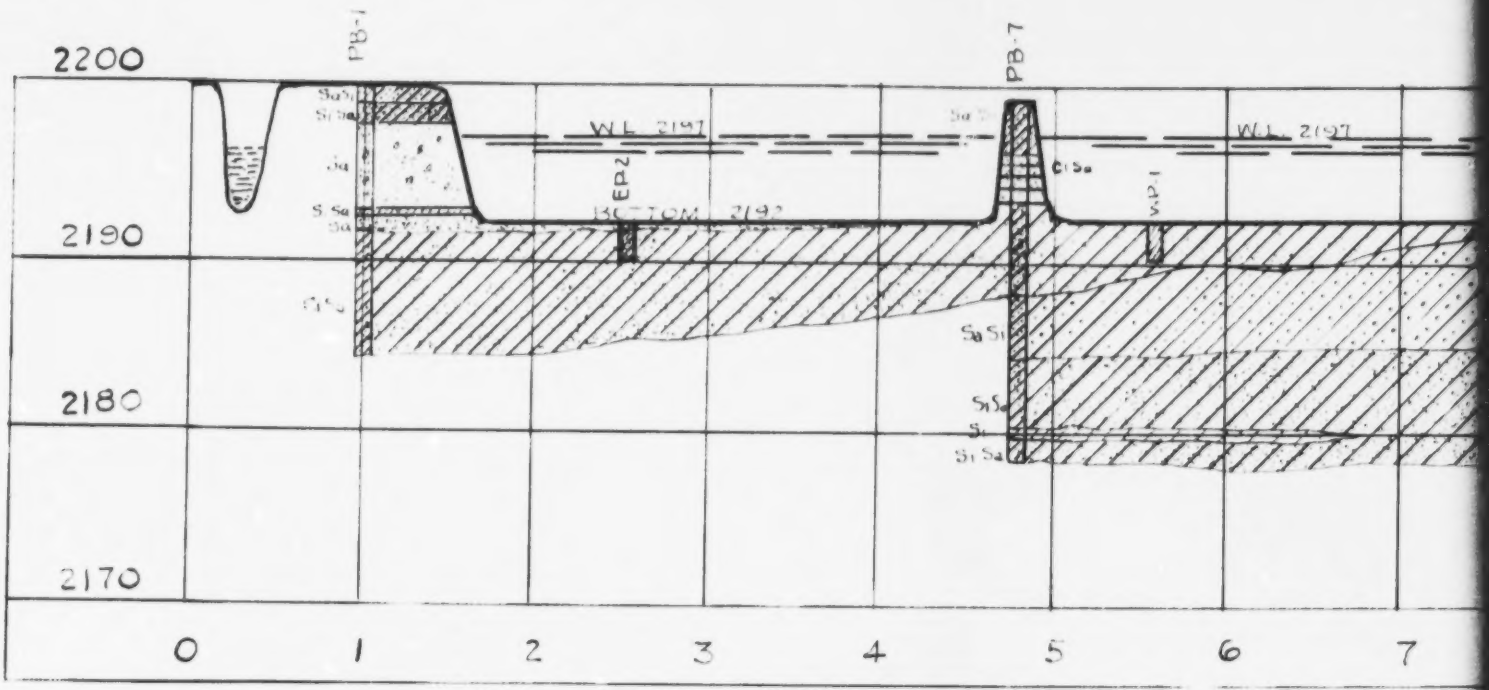
SECTION B-B

Scale
Horizontal 1" = 100'
Vertical 1" = 10'

Note: See Figure 1.2 for Location of Sections

CROSS-SECTIONS OF SOIL HORIZONS AT EAST & WEST LAGOONS

Figure A-1



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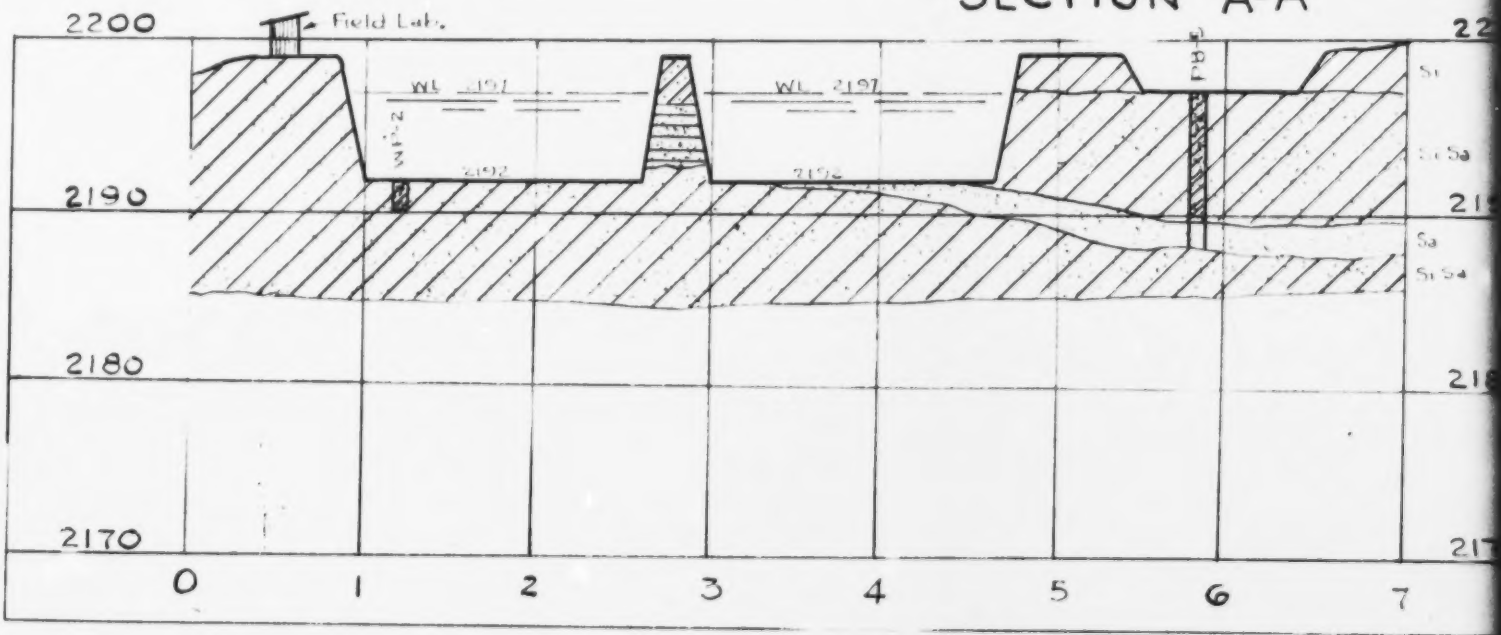
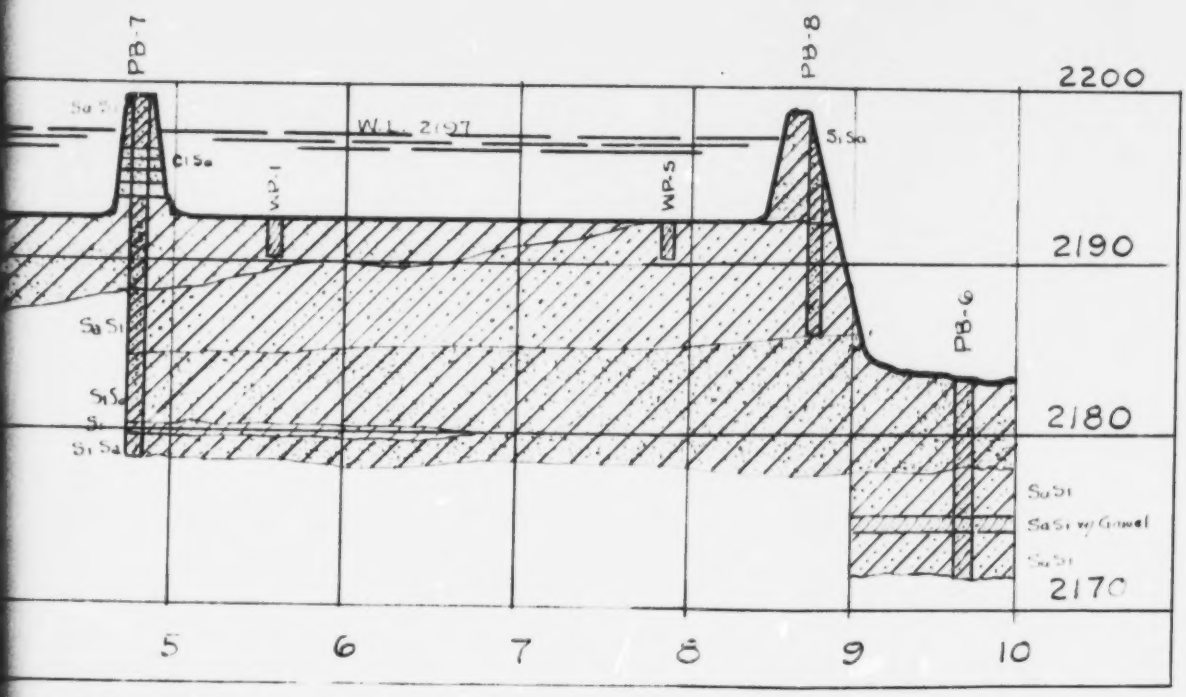
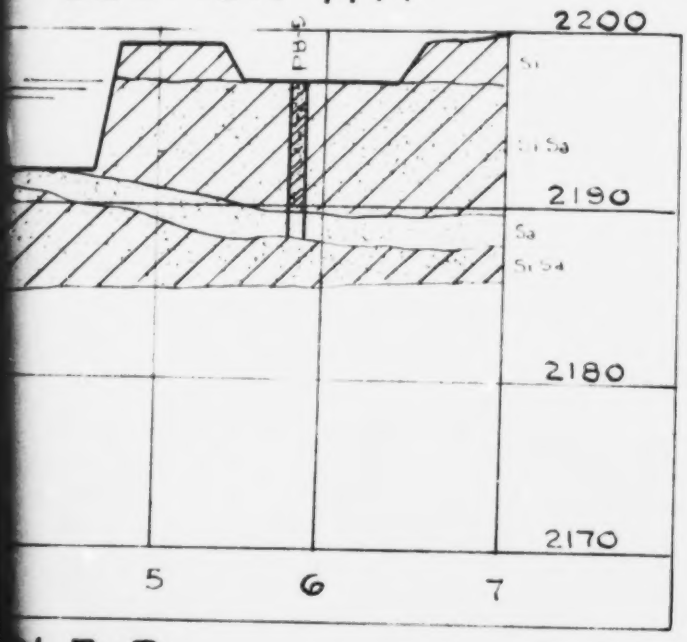


SECTION B-B



SECTION A-A



N B-B

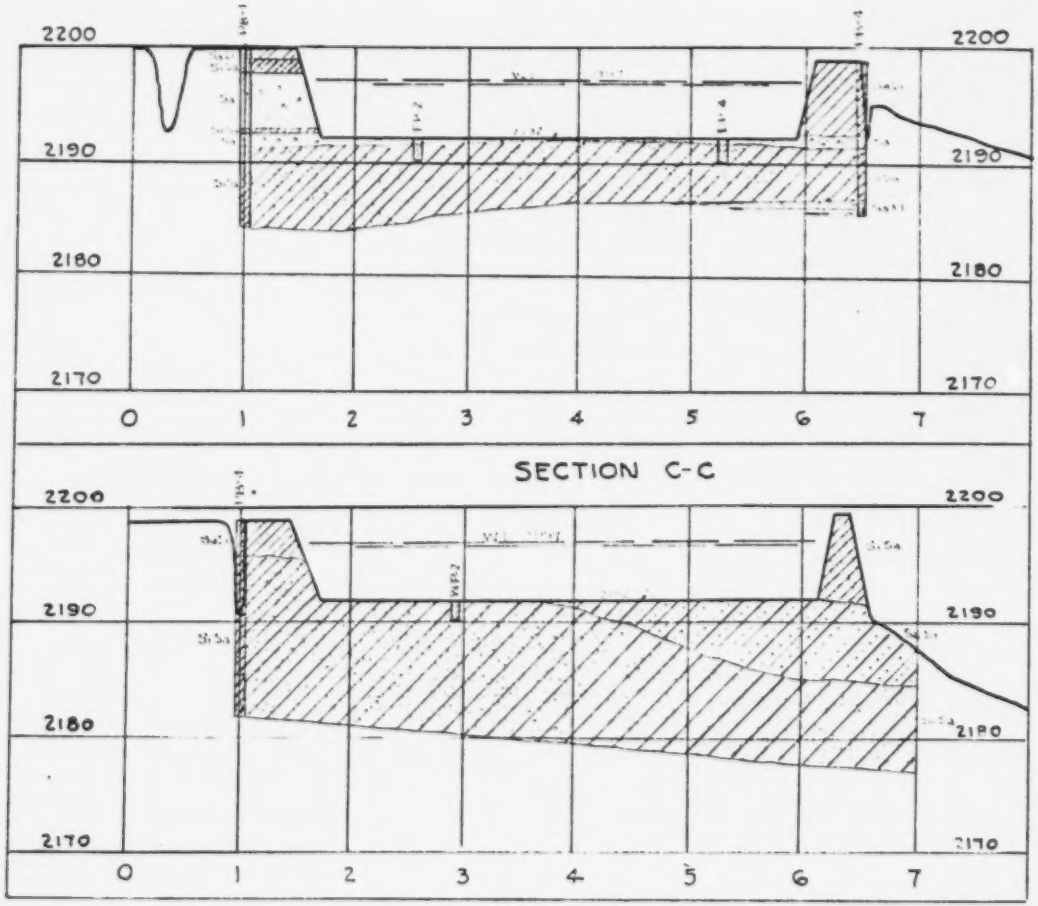
Scale
Horizontal 1" = 100'
Vertical 1" = 10'

Note: See Figure 1.2
For Location of Sections

CROSS-SECTIONS OF SOIL HORIZONS AT EAST & WEST LAGOONS

Figure A-1

SAD



Scale
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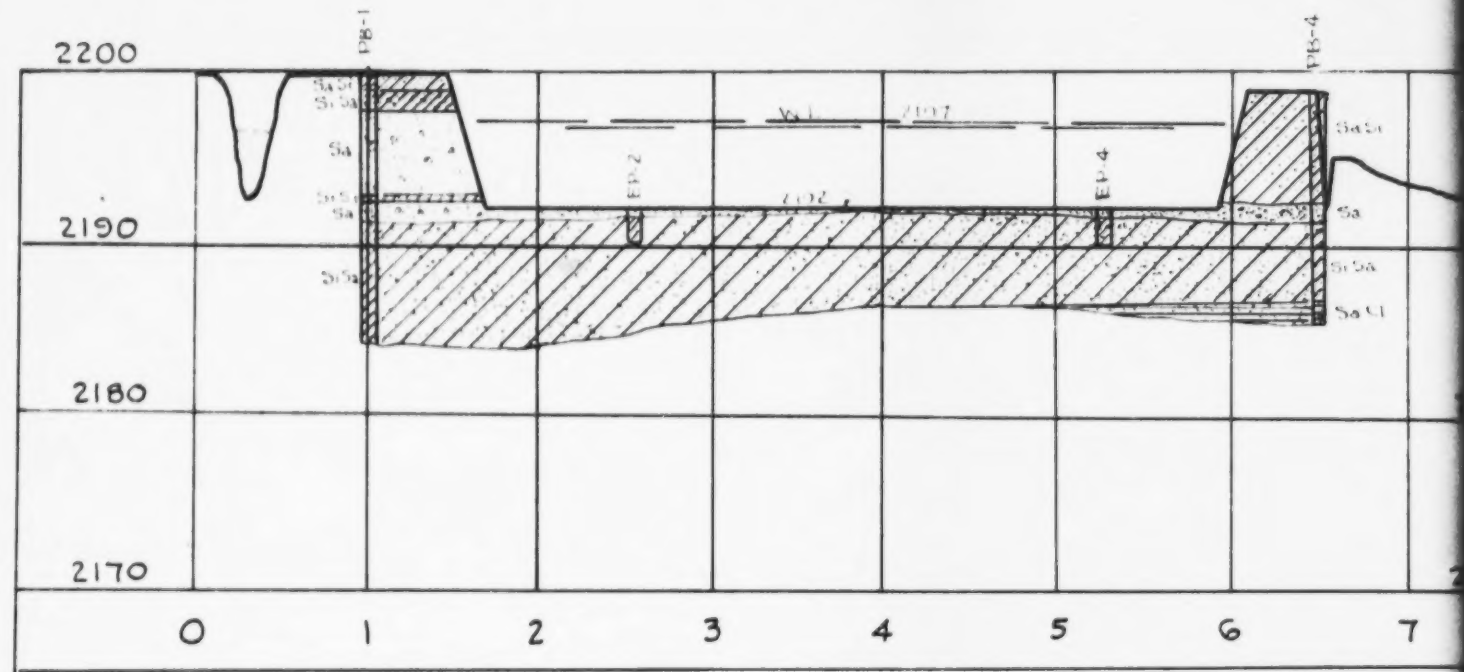
Vertical 1"=10'

Note: See Figure 1.2
For Location of Sections

CROSS-SECTIONS OF SOIL HORIZONS AT EAST & WEST LAGOONS

Figure A-2



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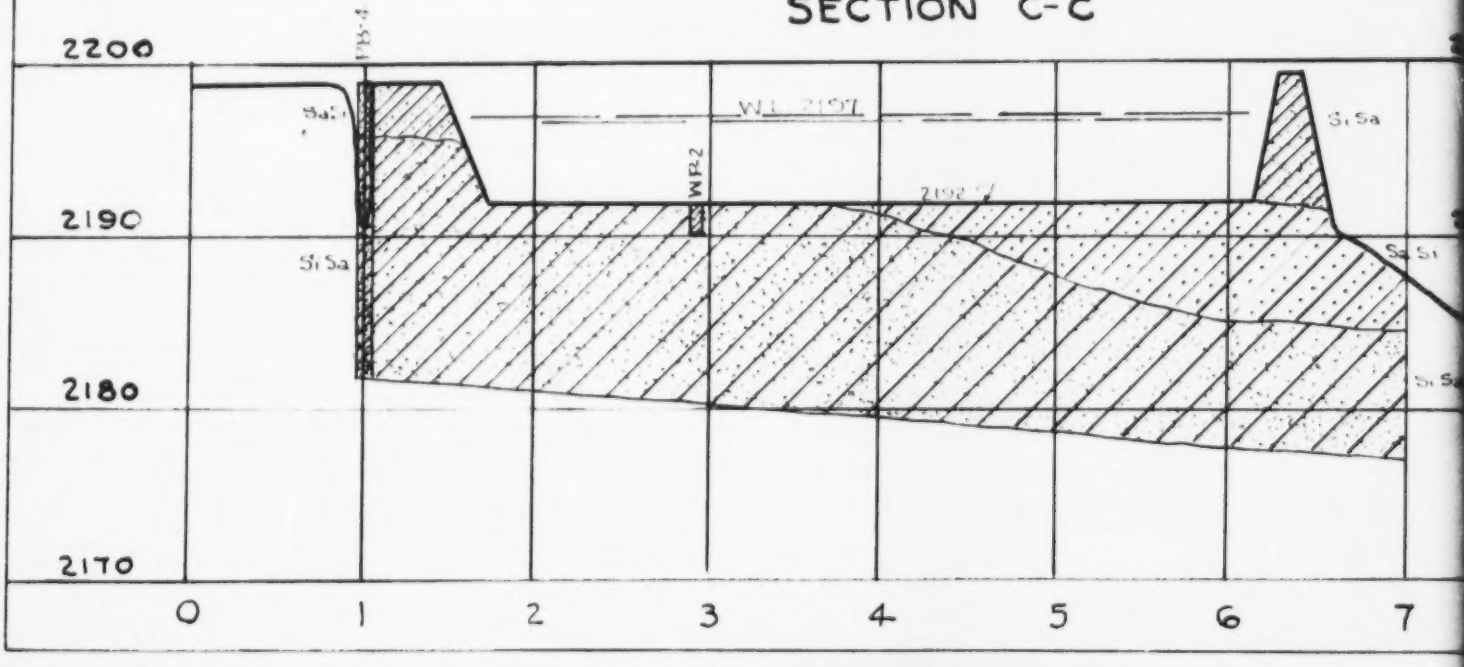

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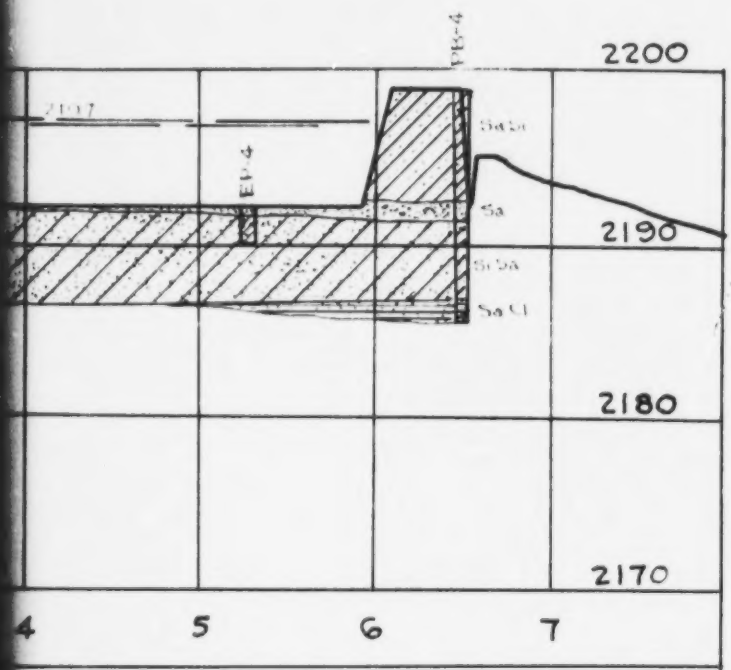

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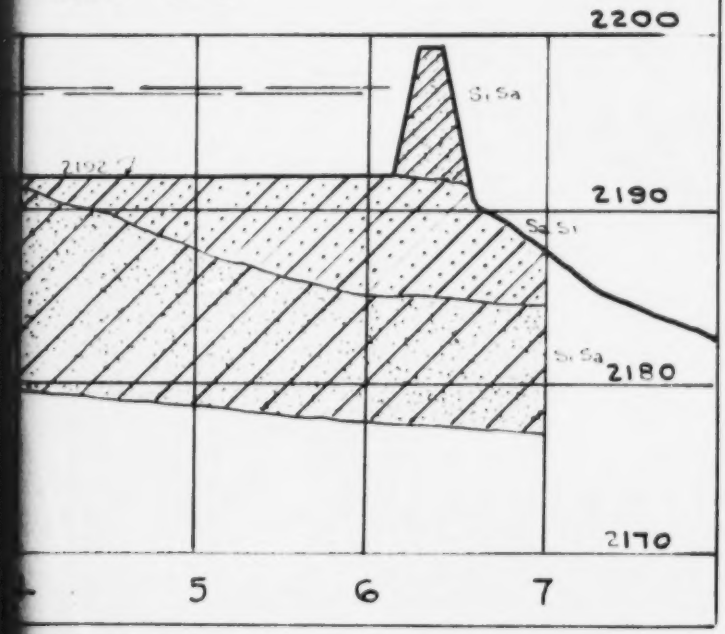


TION D-D

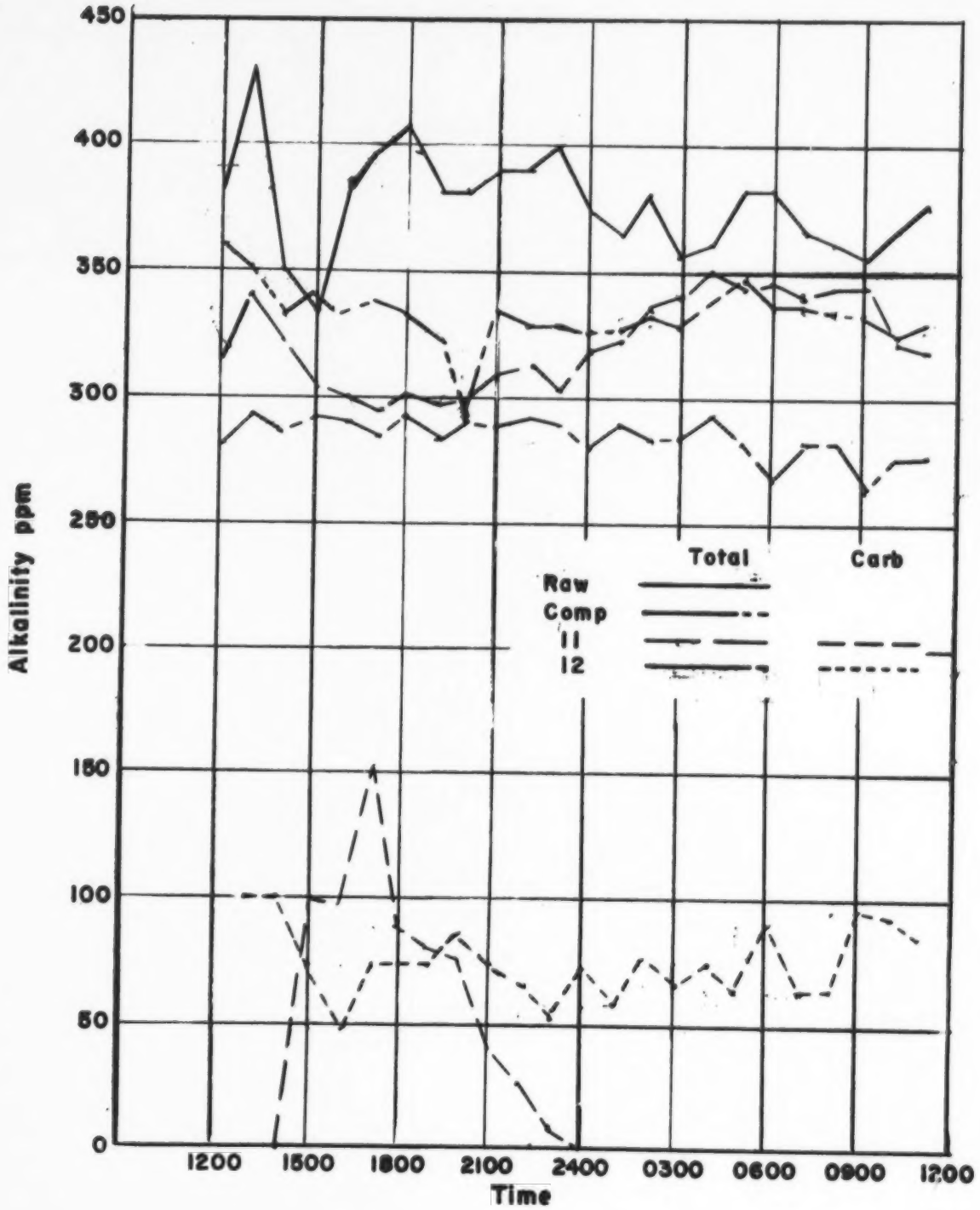
Scale
Horizontal: 1"=100'
Vertical: 1"=10'

Note: See Figure 1.2
For Location of Sections

CROSS-SECTIONS OF SOIL HORIZONS AT EAST & WEST LAGOONS

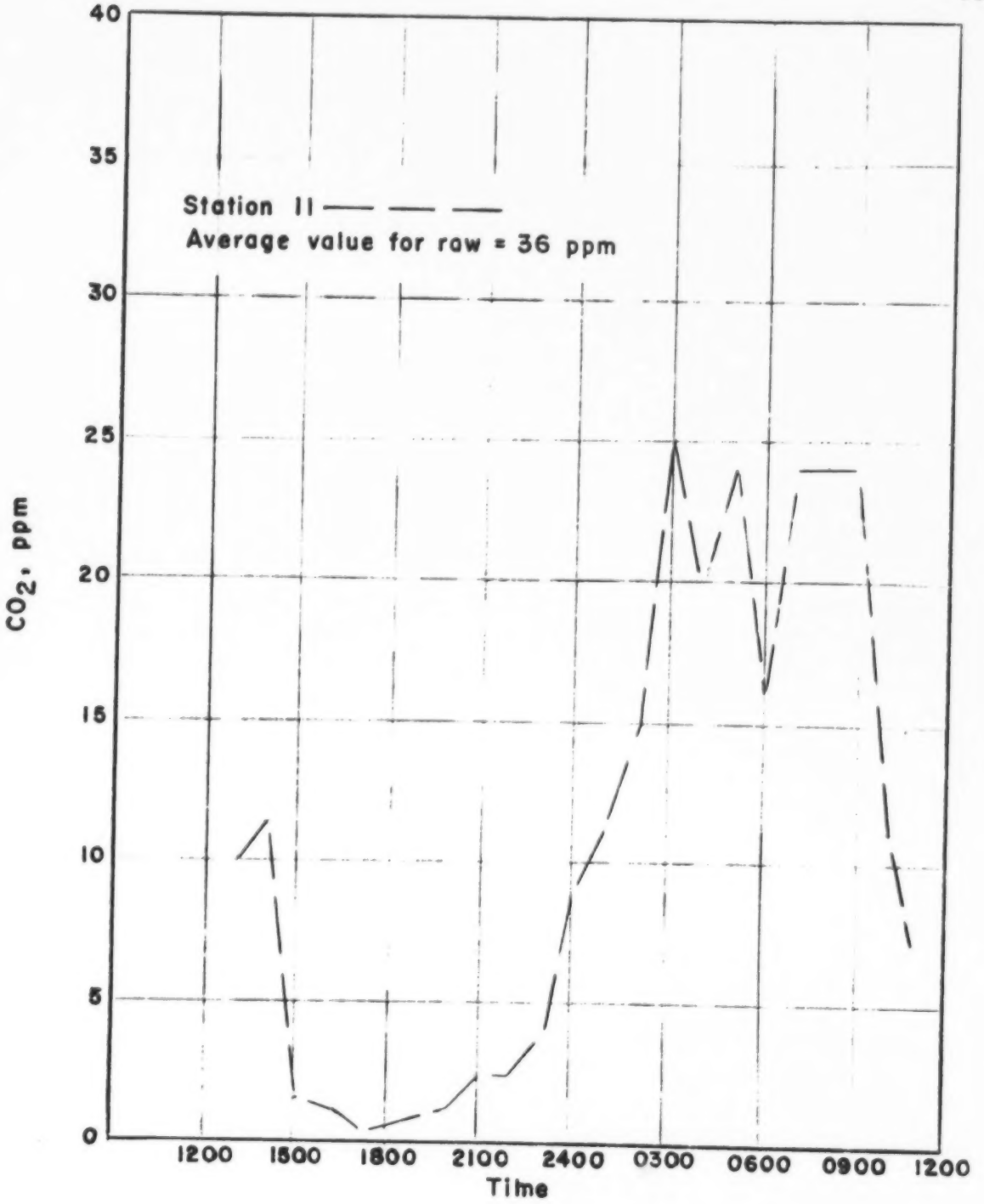
Figure A-2

APPENDIX B



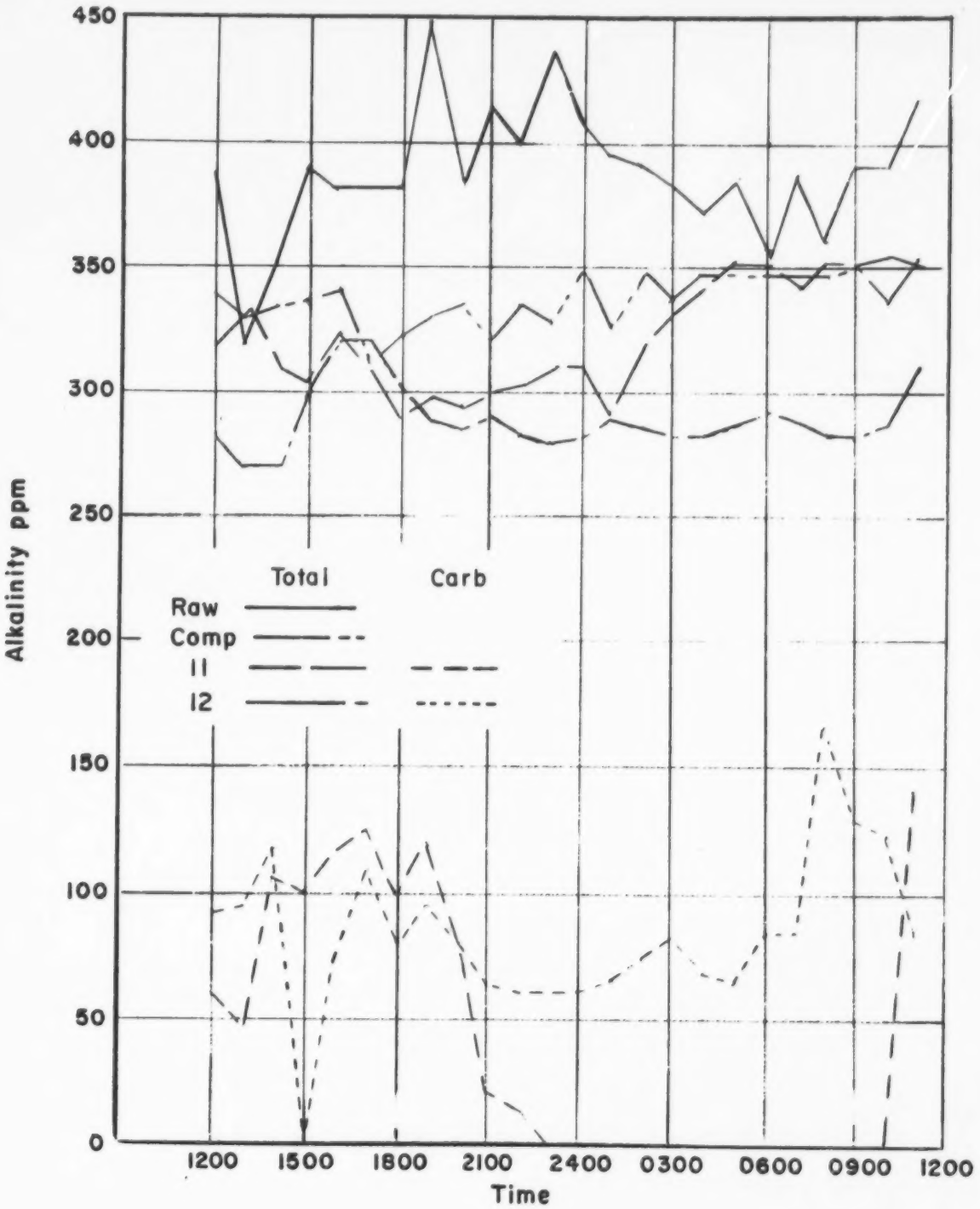
Alkalinity Intensive Sampling
6-11-62, 6-12-62

Figure B-1



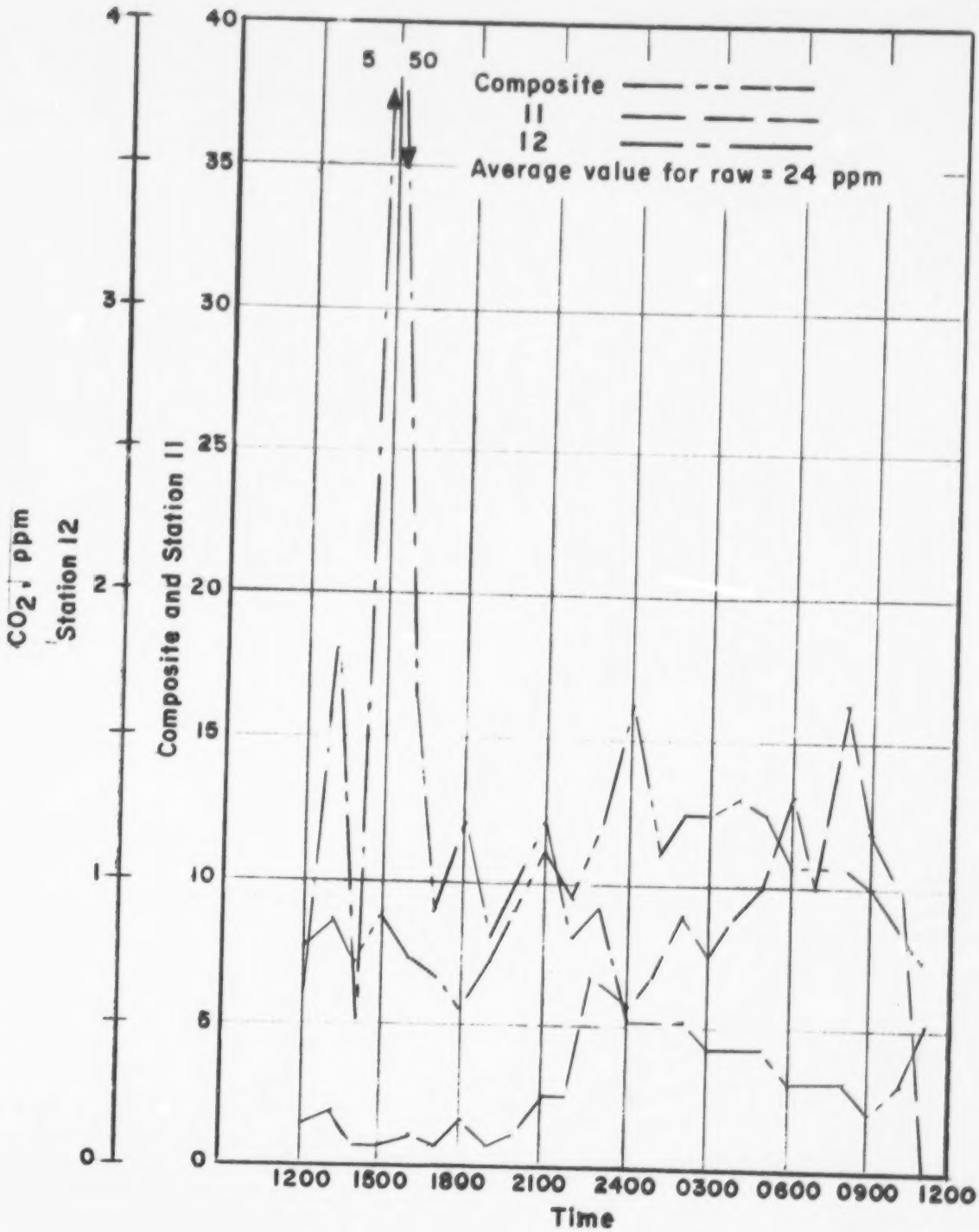
CO_2, Intensive Sampling
6-11-62, 6-12-62

Figure B-2



Alkalinity Intensive Sampling
6-19-62, 6-20-62

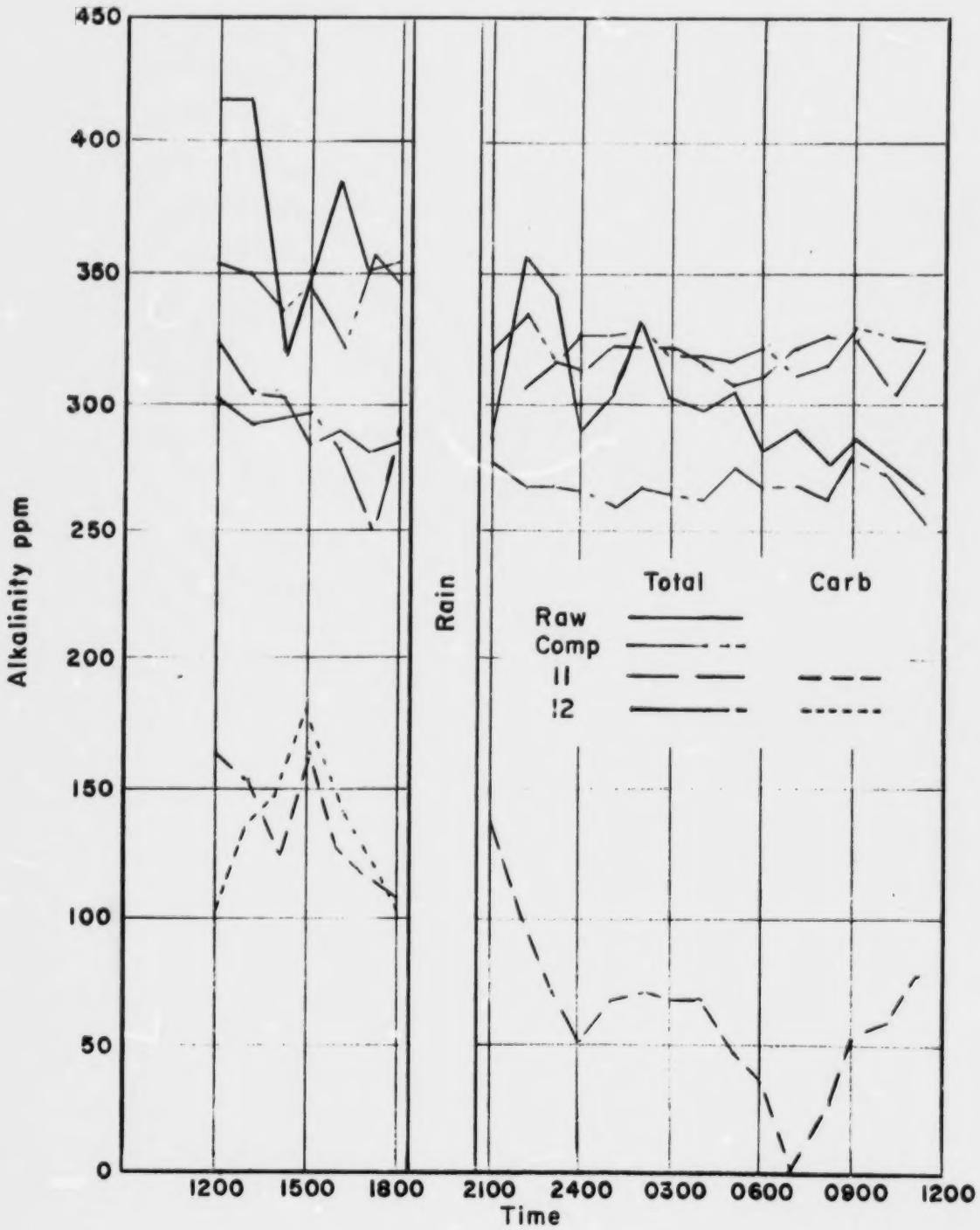
Figure B-3



CO_2, Intensive Sampling

6-19-62, 6-20-62

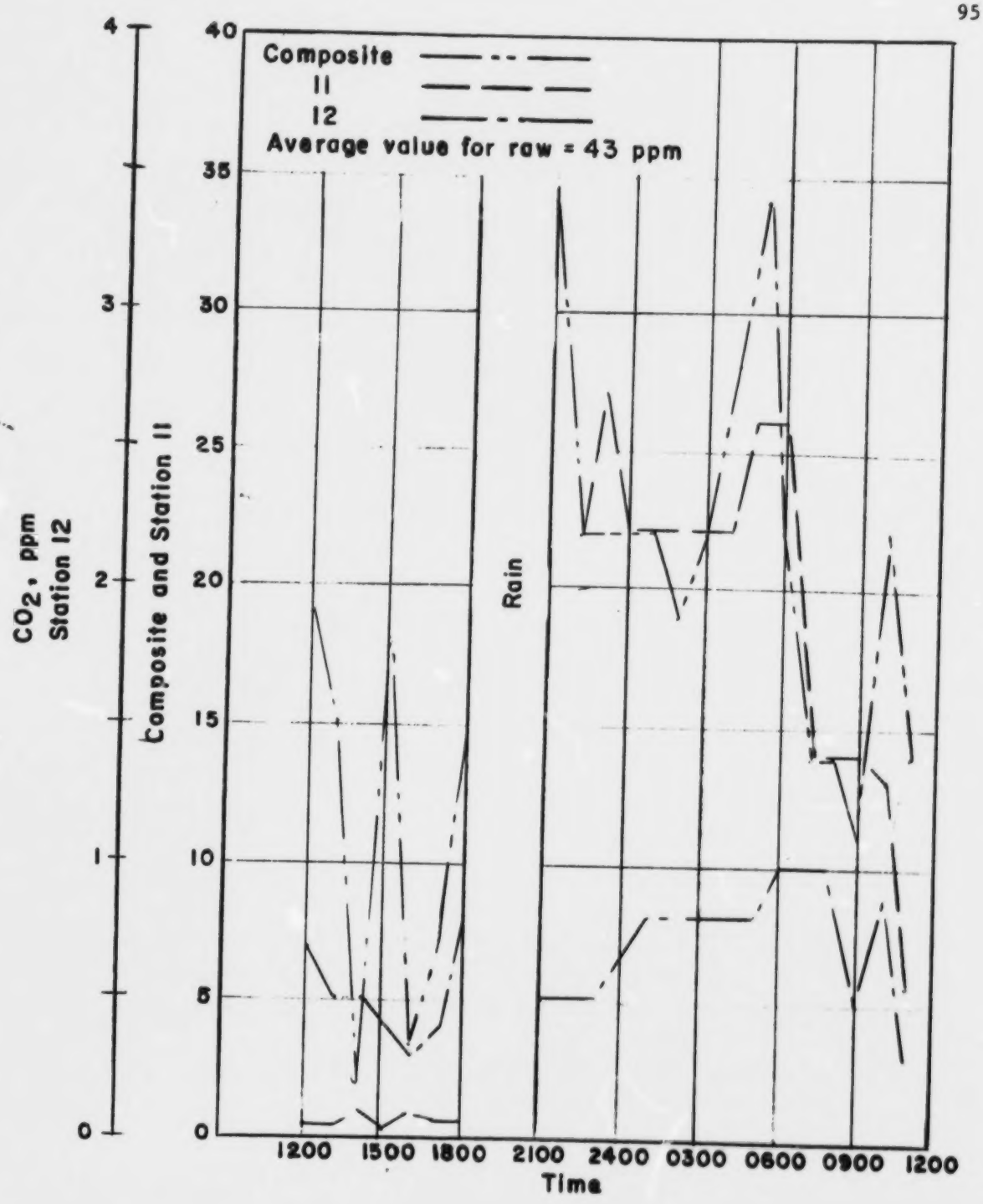
Figure B-4



Alkalinity Intensive Sampling

6-27-62, 6-28-62

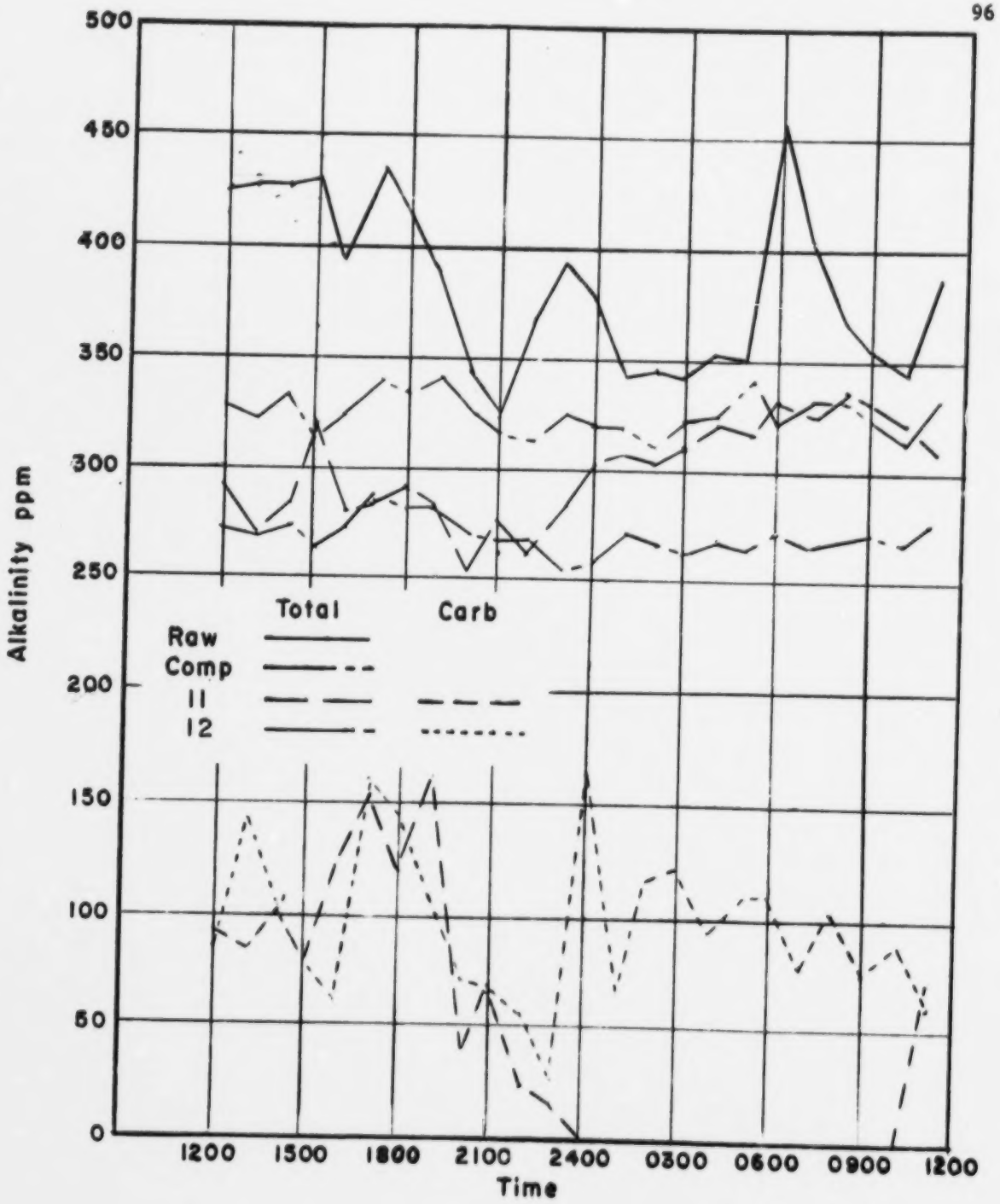
Figure B-5



CO_2, Intensive Sampling

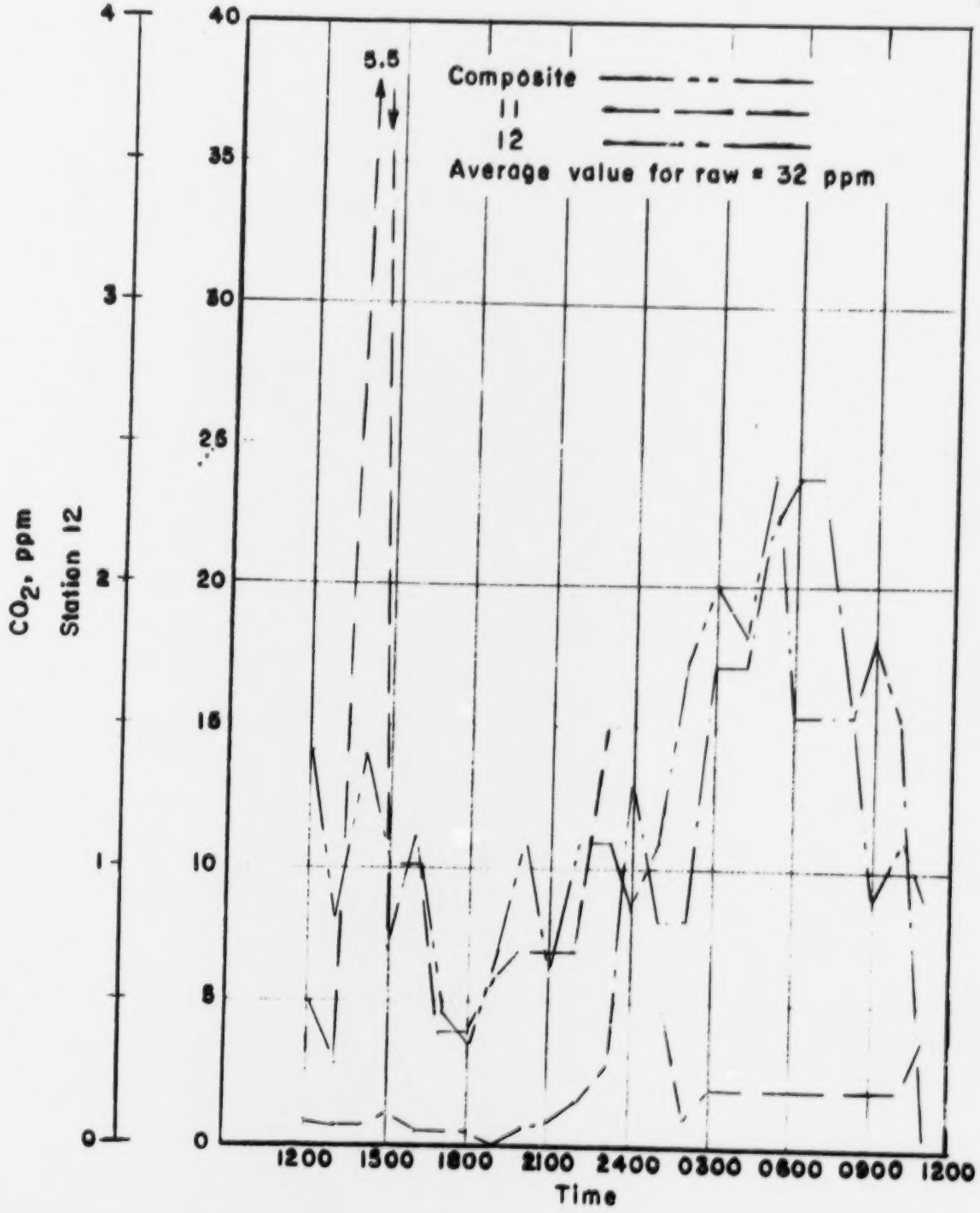
6-27.-62, 6-28-62

Figure B-6



Alkalinity Intensive Sampling
7-5-62, 7-6-62

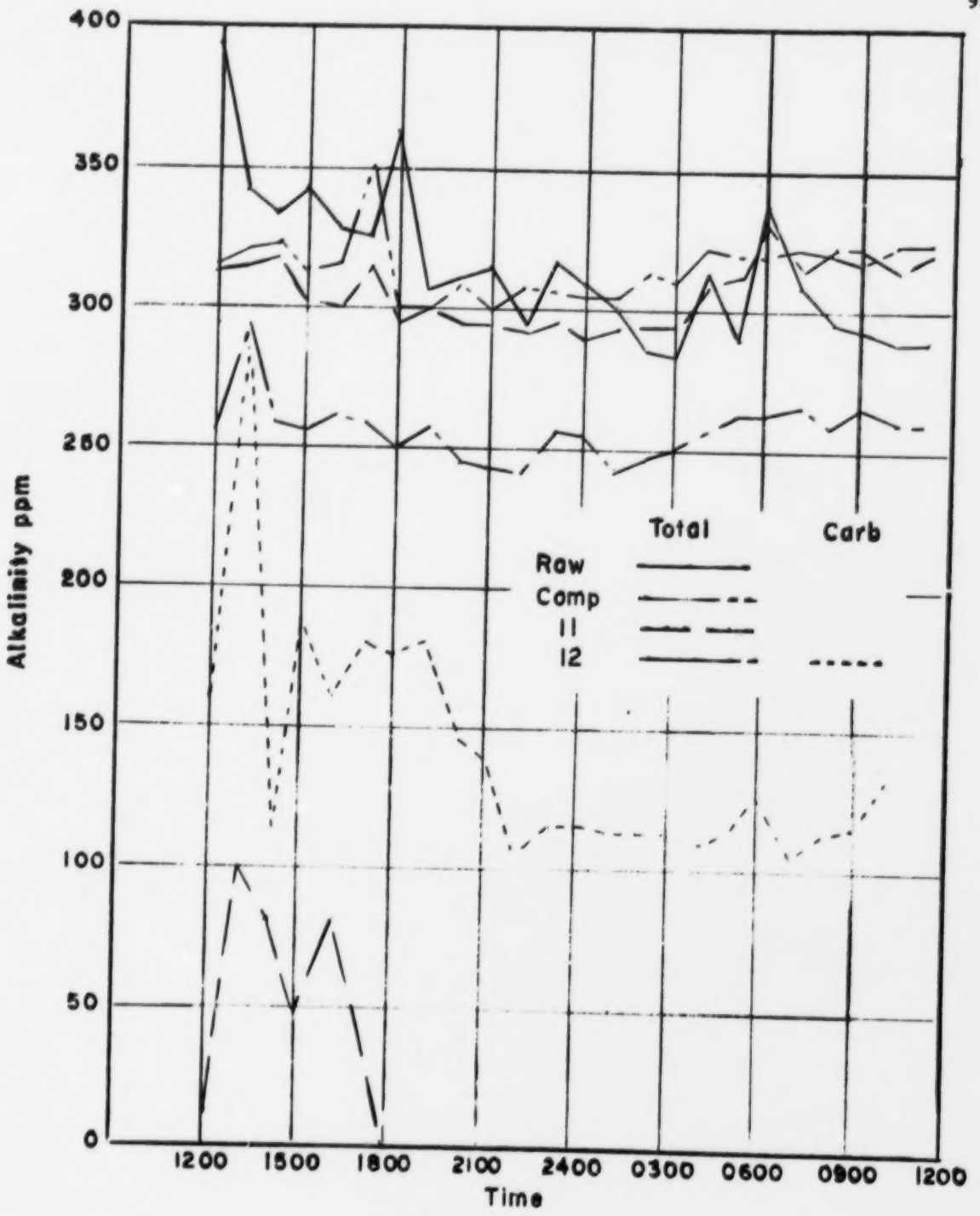
Figure B-7



CO_2, Intensive Sampling

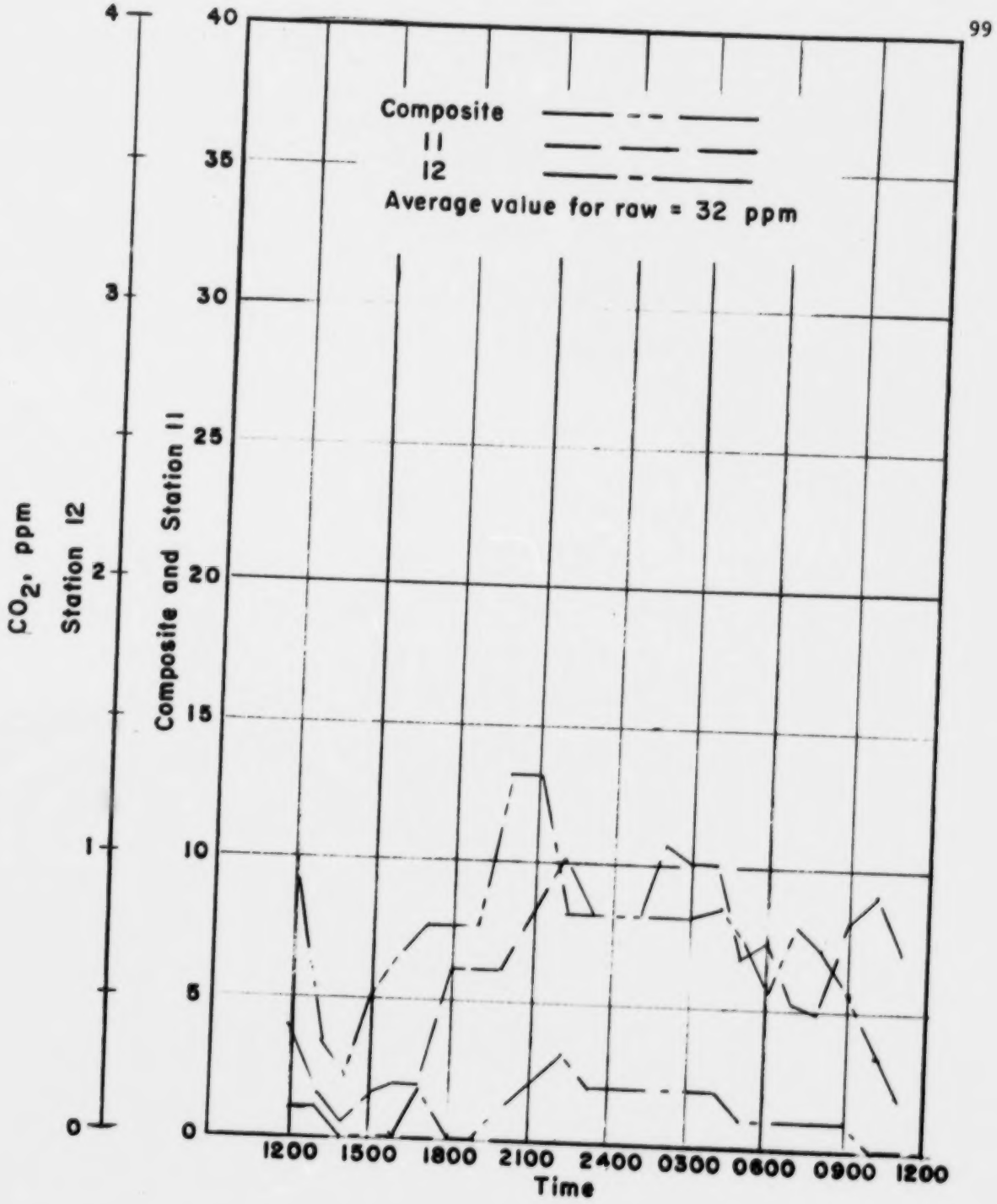
7-5-62, 7-6-62

Figure B-8



Alkalinity Intensive Sampling
7-13-62, 7-14-62

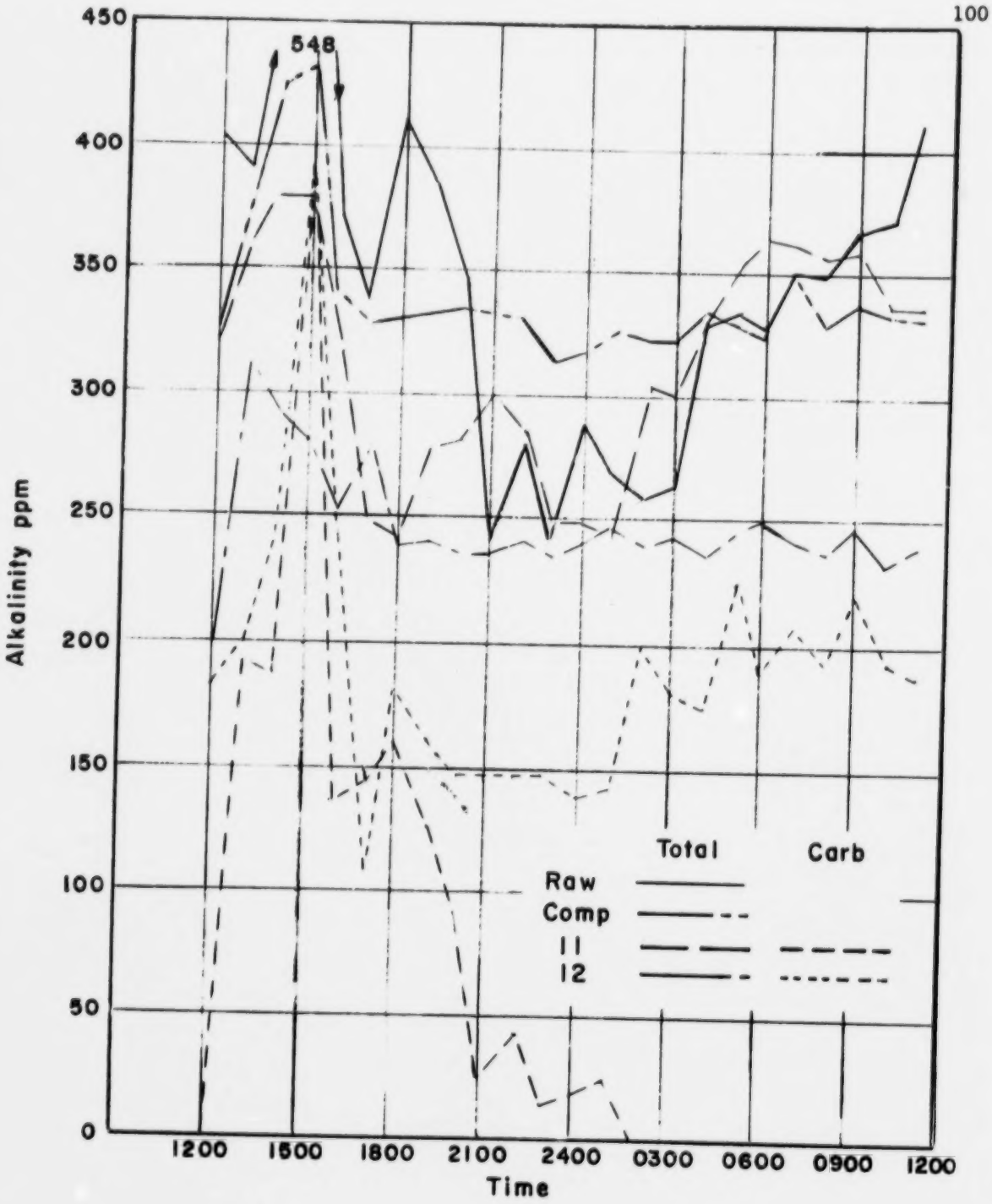
Figure B-9



CO_2, Intensive Sampling

7-13-62, 7-14-62

Figure B-10



Alkalinity Intensive Sampling
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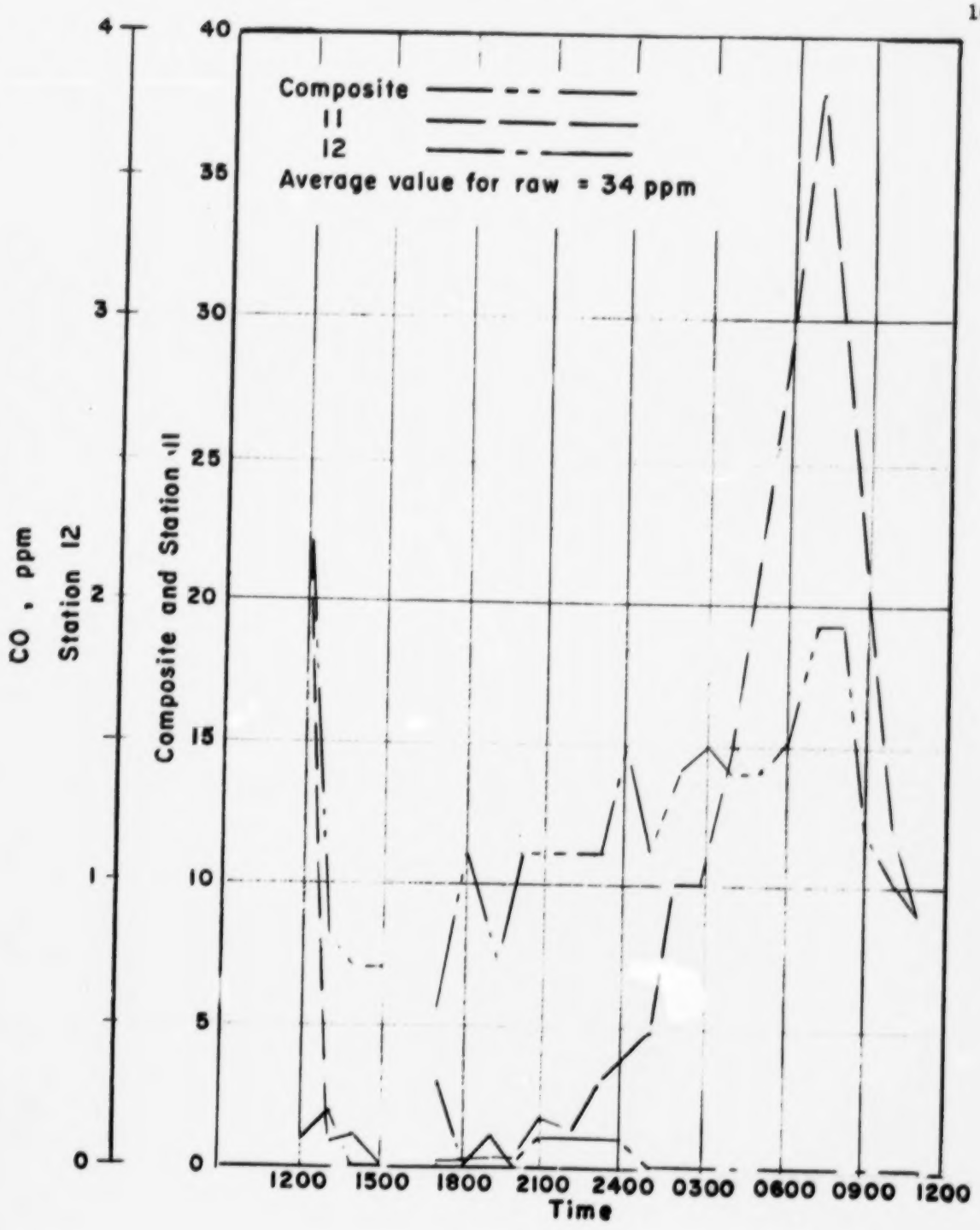
Figure B-11



CO_2, Intensive Sampling

7-21-62, 7-22-62

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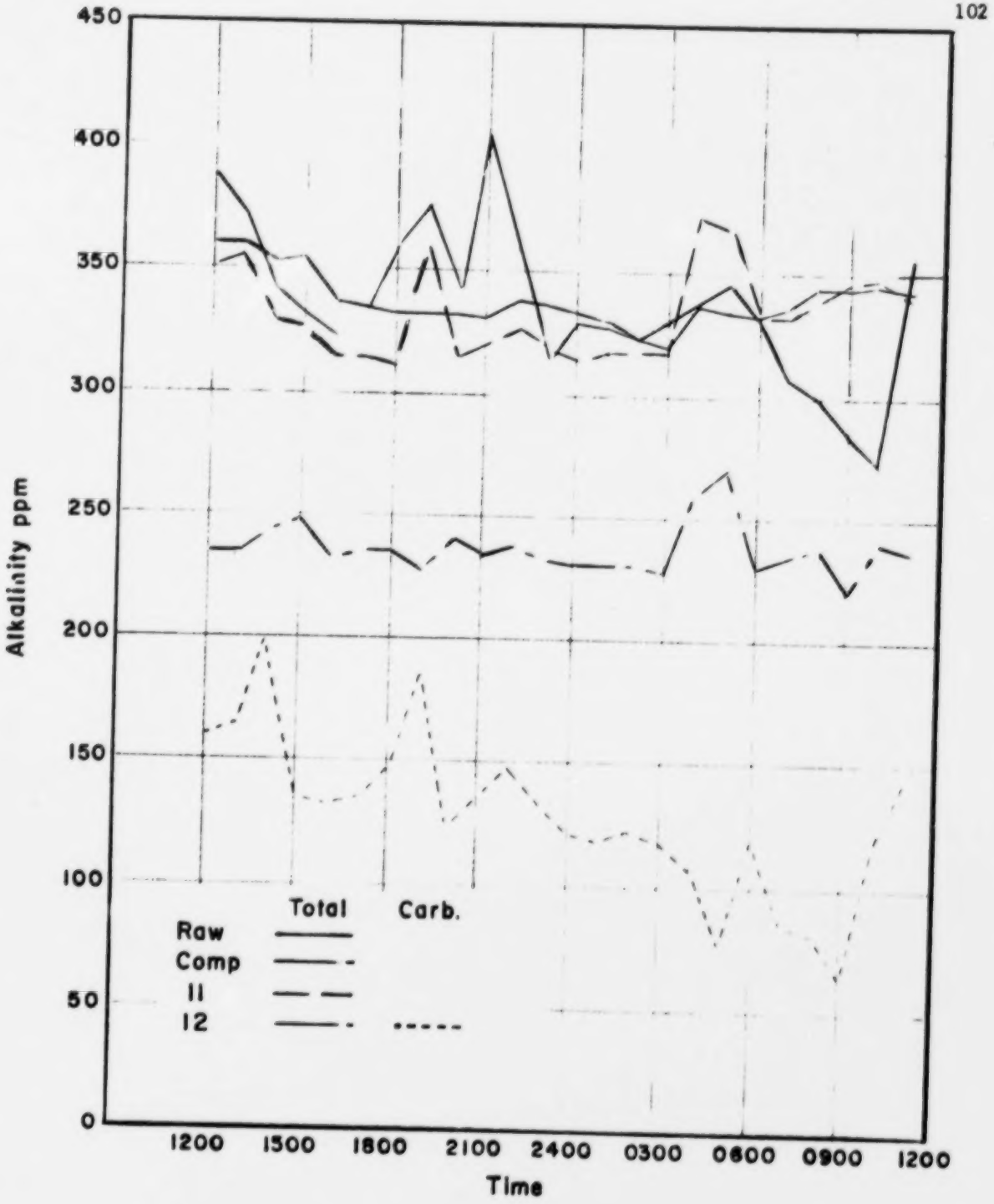
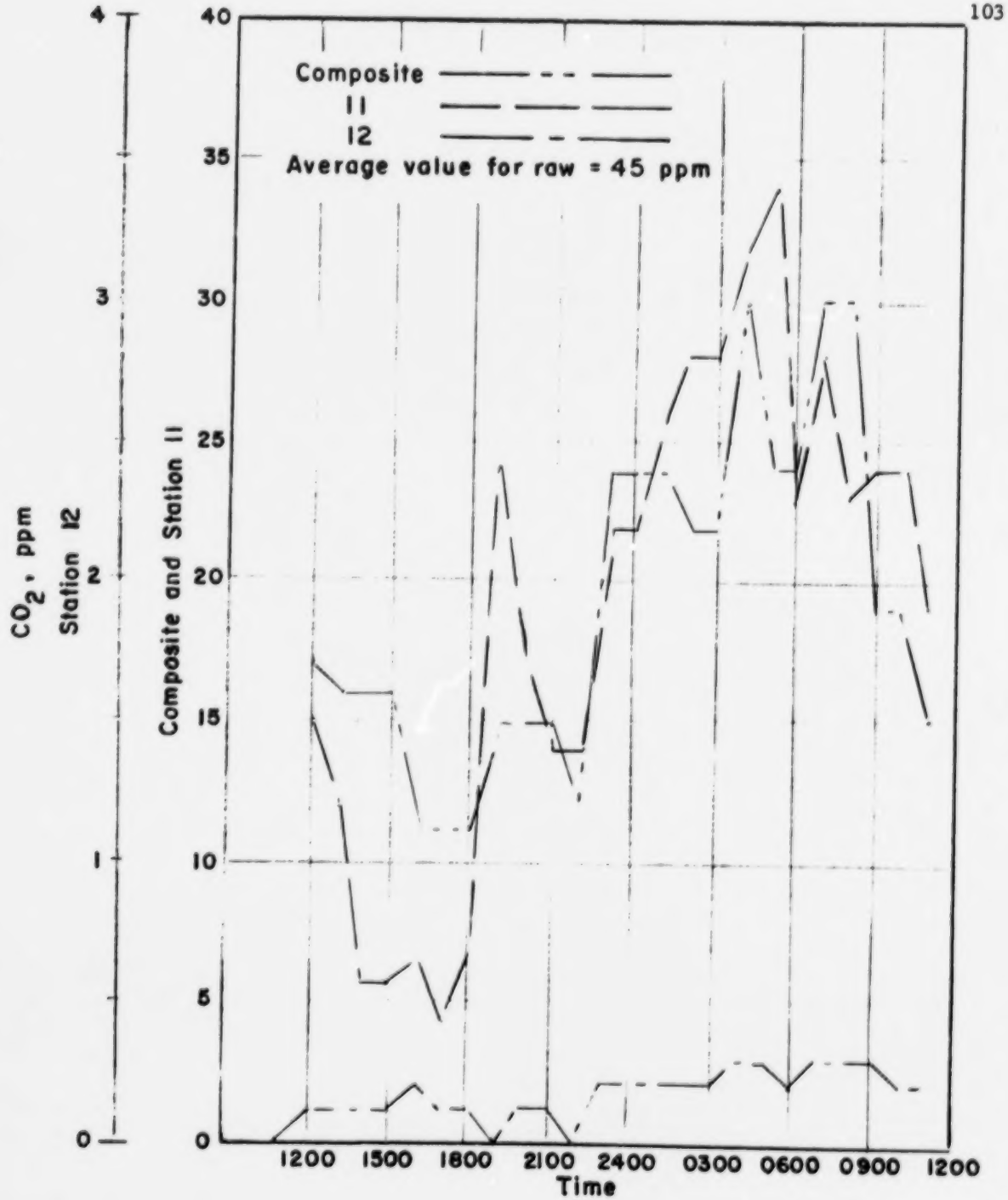


Alkalinity Intensive Sampling
7-29-62, 7-30-62

Figure B-13



CO_2, Intensive Sampling

7-29-62, 7-30-62

Figure B-14

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